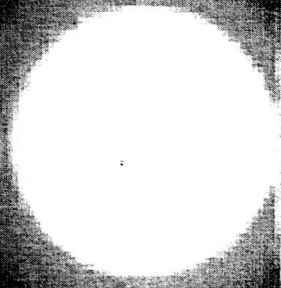


# *Bio-Molecular-Engineering*

*An approach to nano-scale design  
and construction*





Tools and materials from biology to manipulate matter...



*Nano-scale bio-tools and bio-materials*

DNA/RNA, lipids, sugars, proteins, and processes...

# Materials from Biology



*Why use biomolecules for nano tools  
and nano materials?*

**Because biomolecules:**

*Self-assemble*

*Molecular recognition*

*Adaptable and evolve s & f*

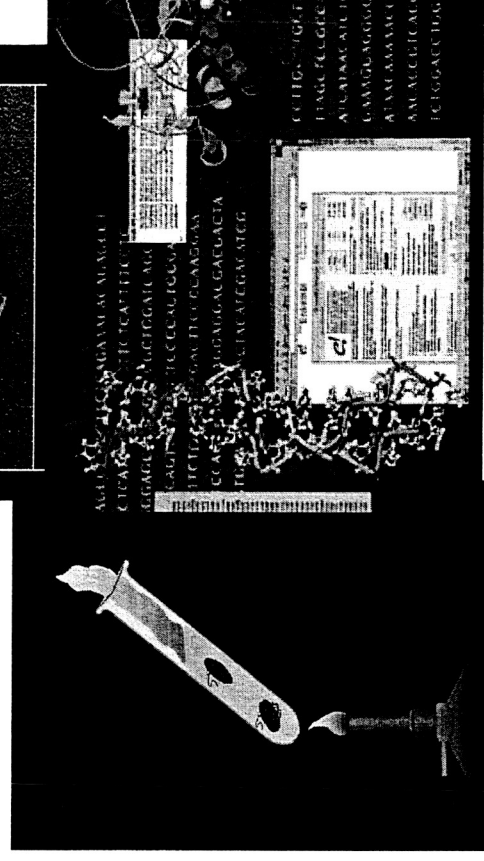
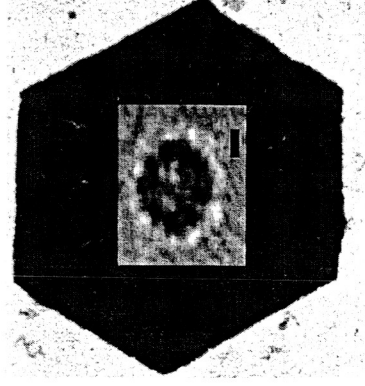
*Form dynamic or crystalline structures*

**And...**

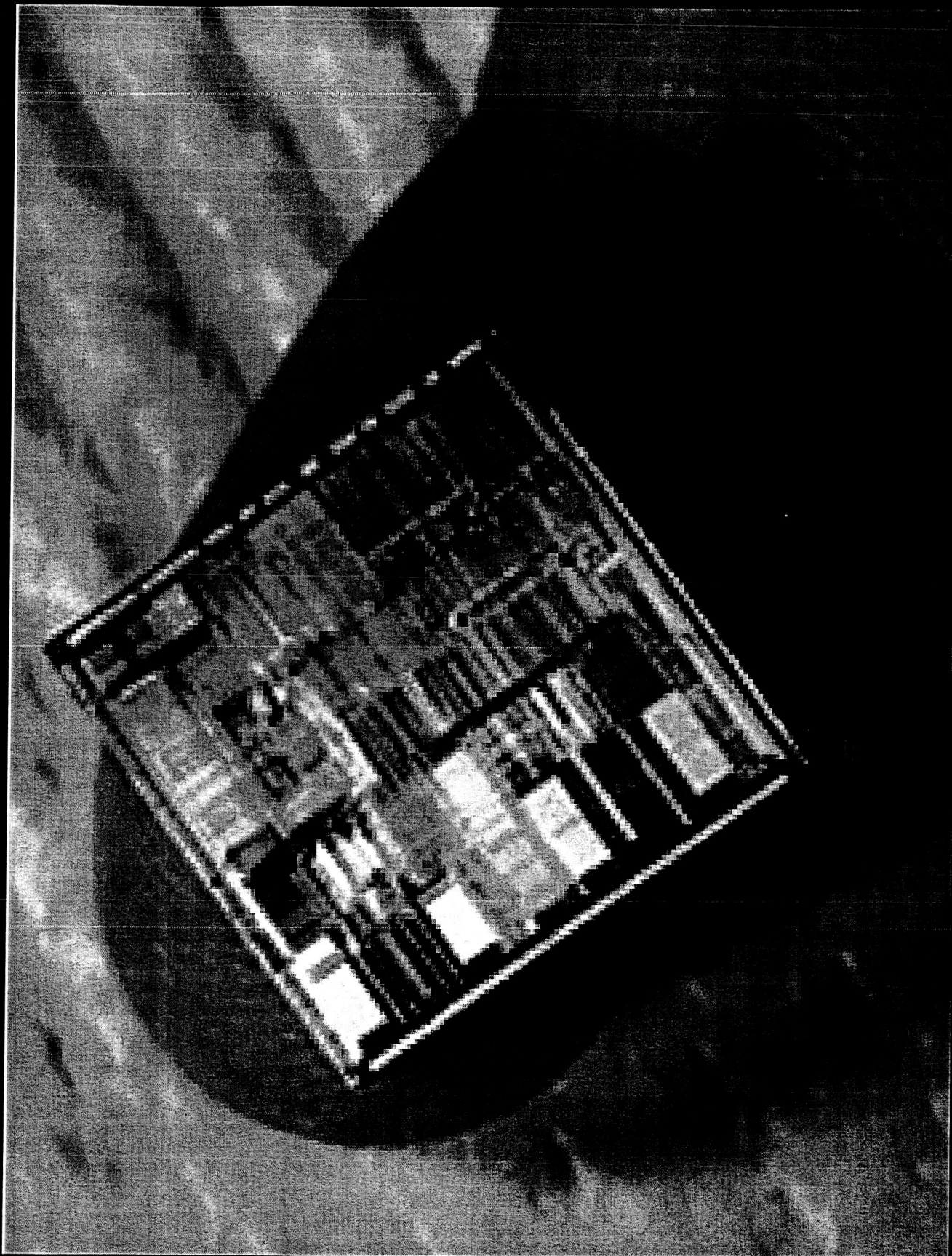
# Bio-Molecular-Engineering

*Because: We have what we need to use them...*

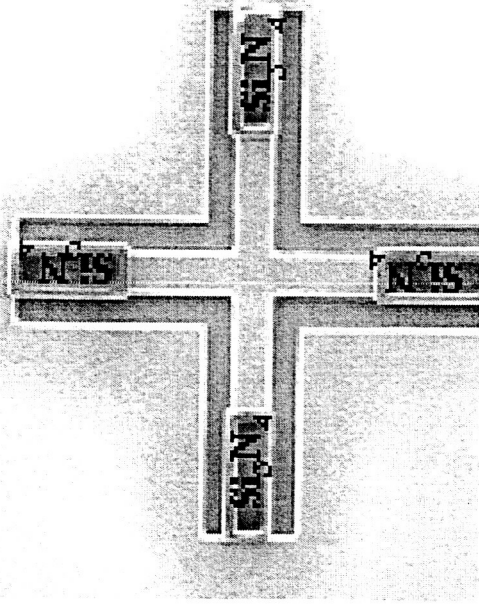
- Electron microscopy
- AFM/STM
- Crystallography
- Biochemistry
- Bioinformatics
- Genomics/proteomics
- Genetic engineering
- Computation molecular design



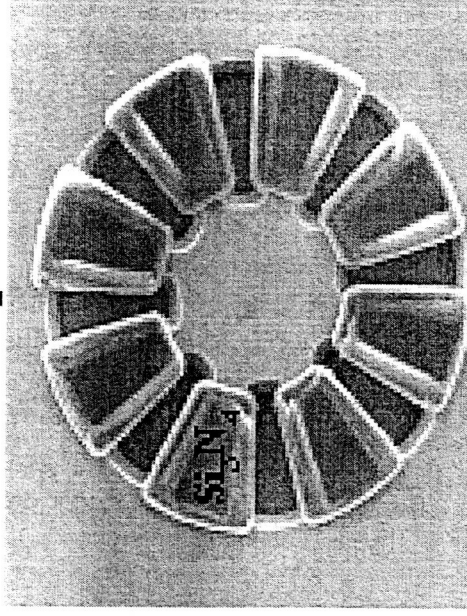




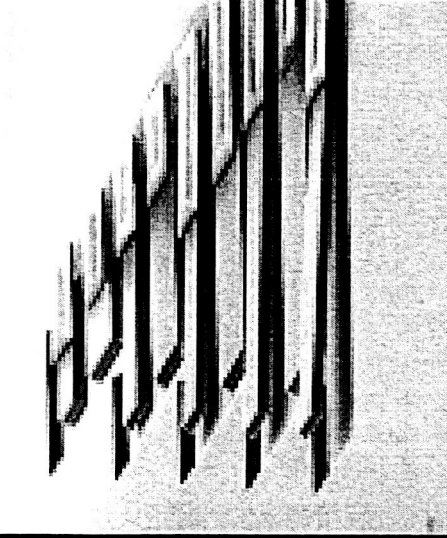
Suspended crosses



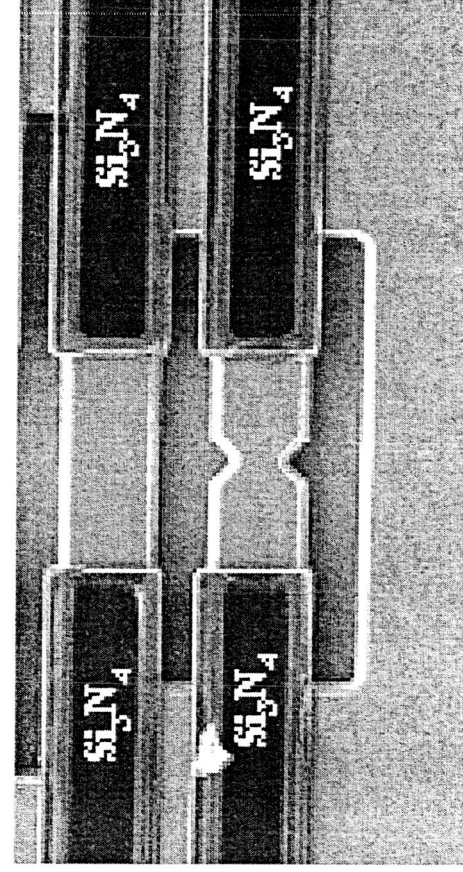
Trampolines

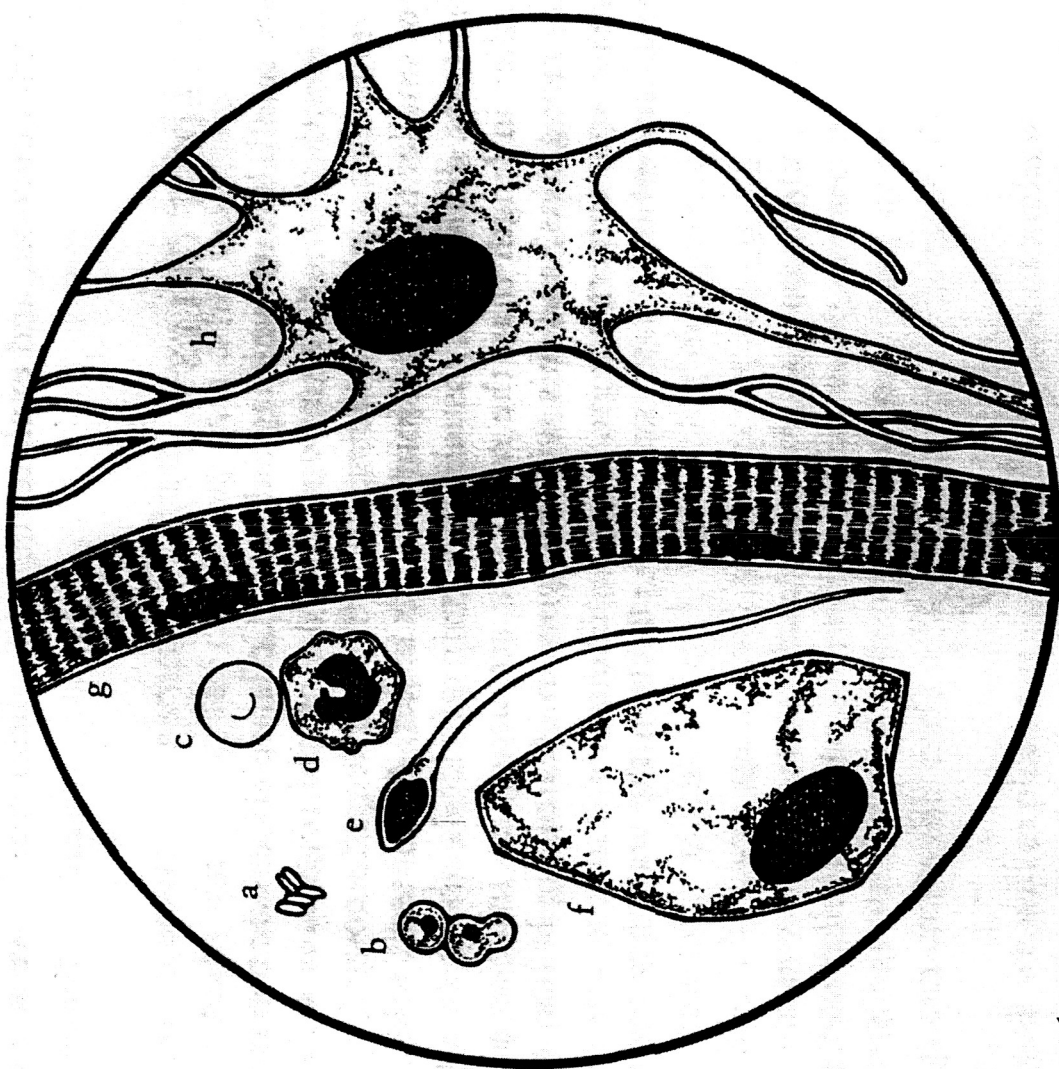


Cantilevers



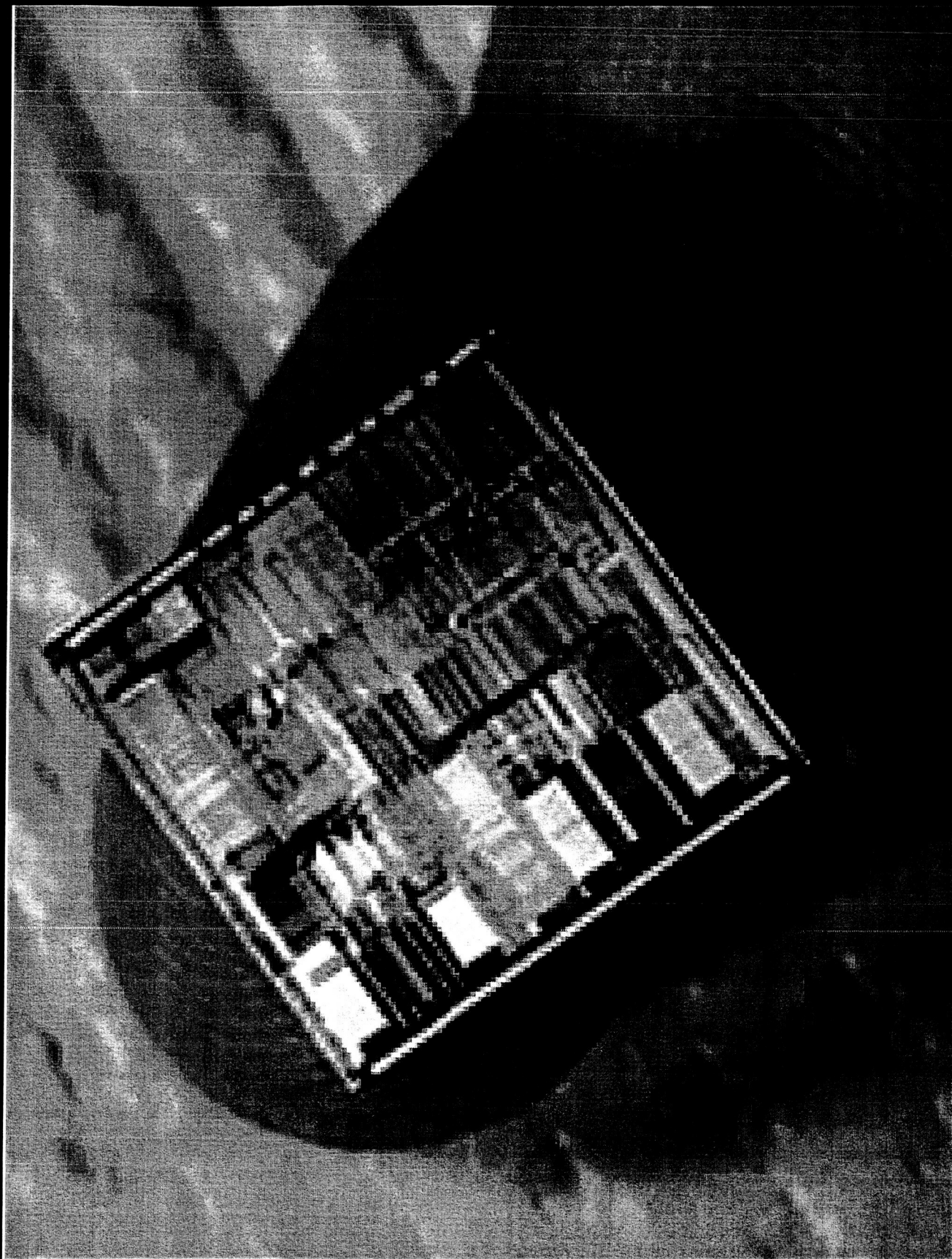
Bridges & notched bridges





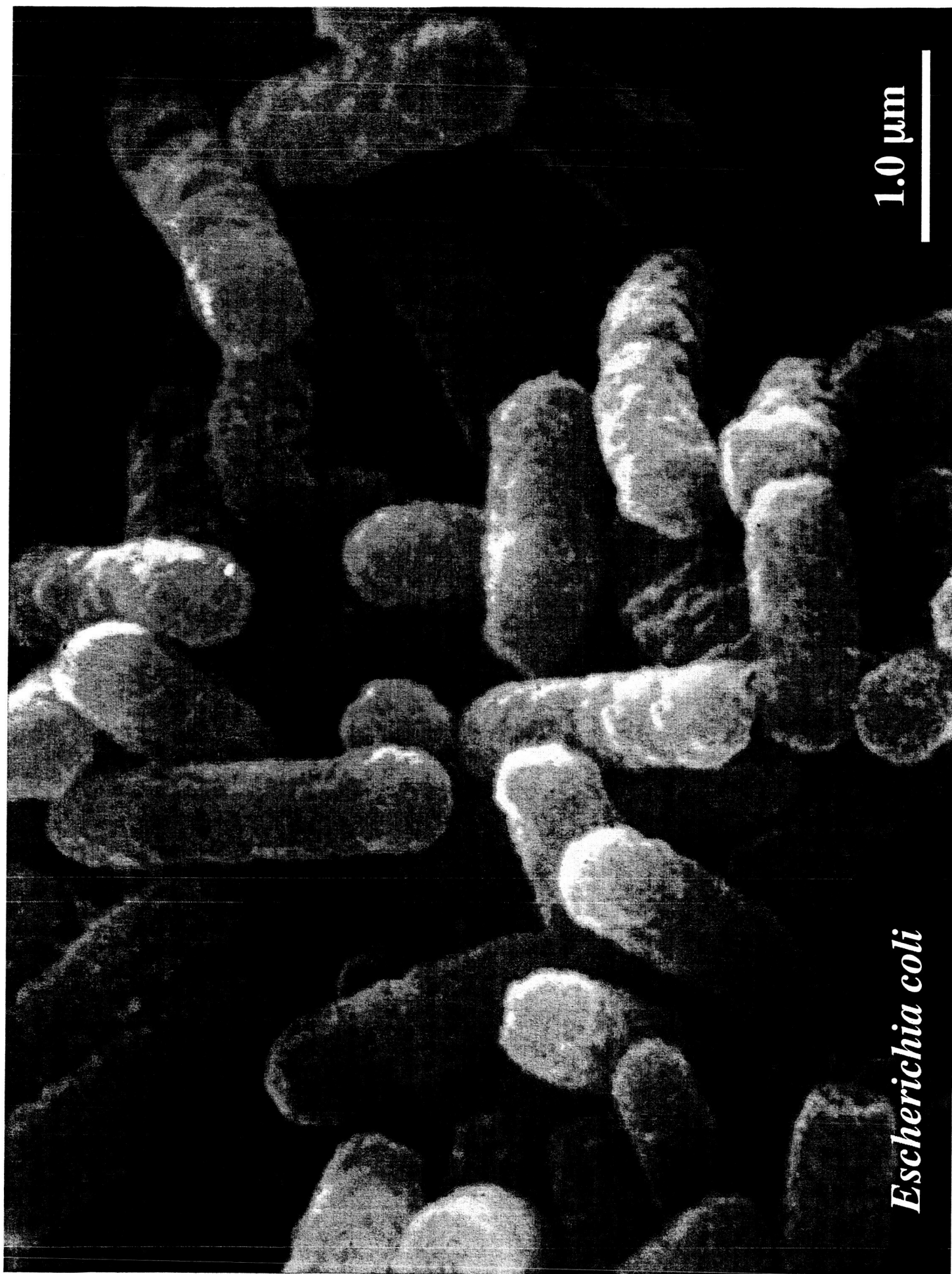
Relative sizes of cells









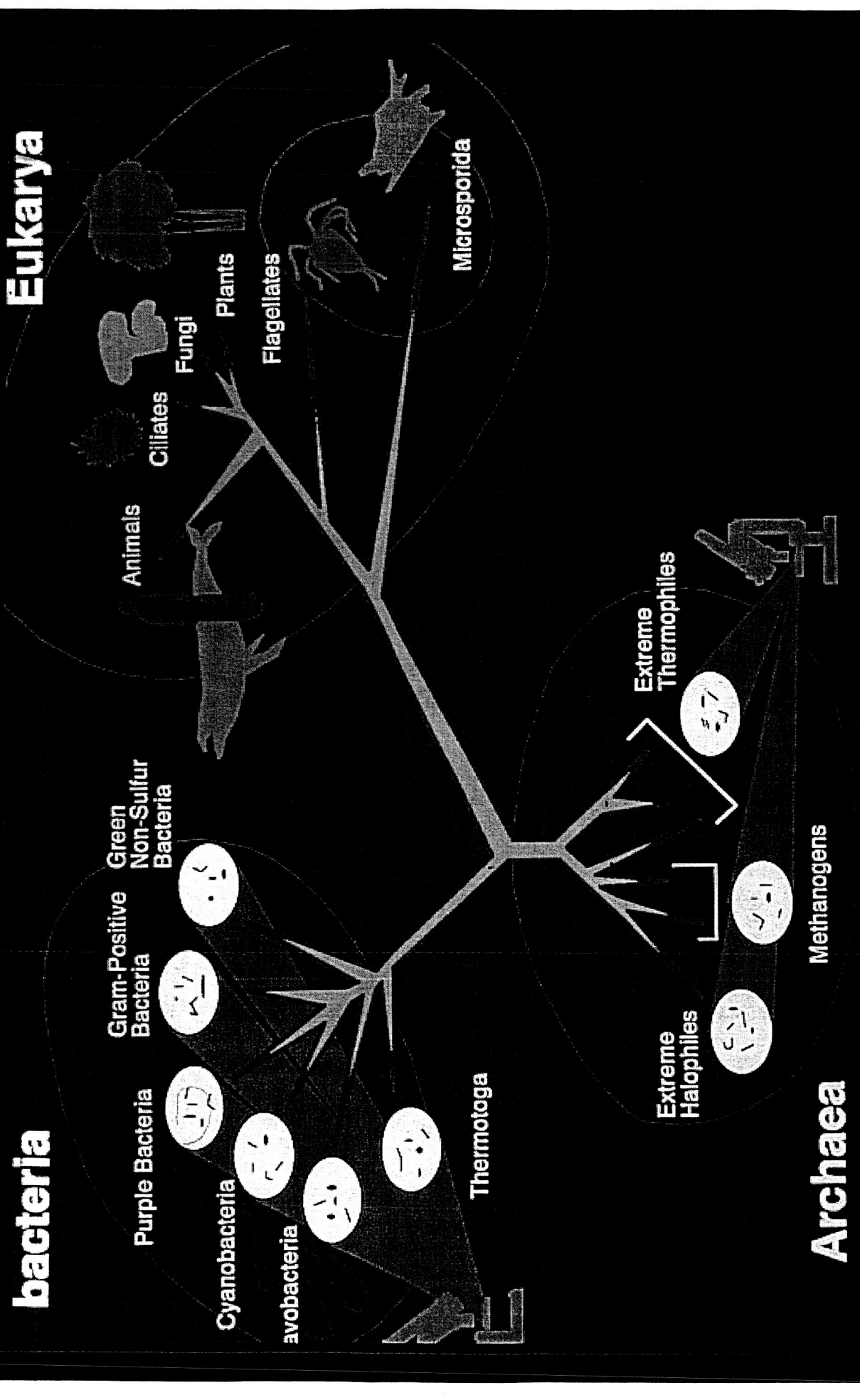


1.0  $\mu\text{m}$

*Escherichia coli*

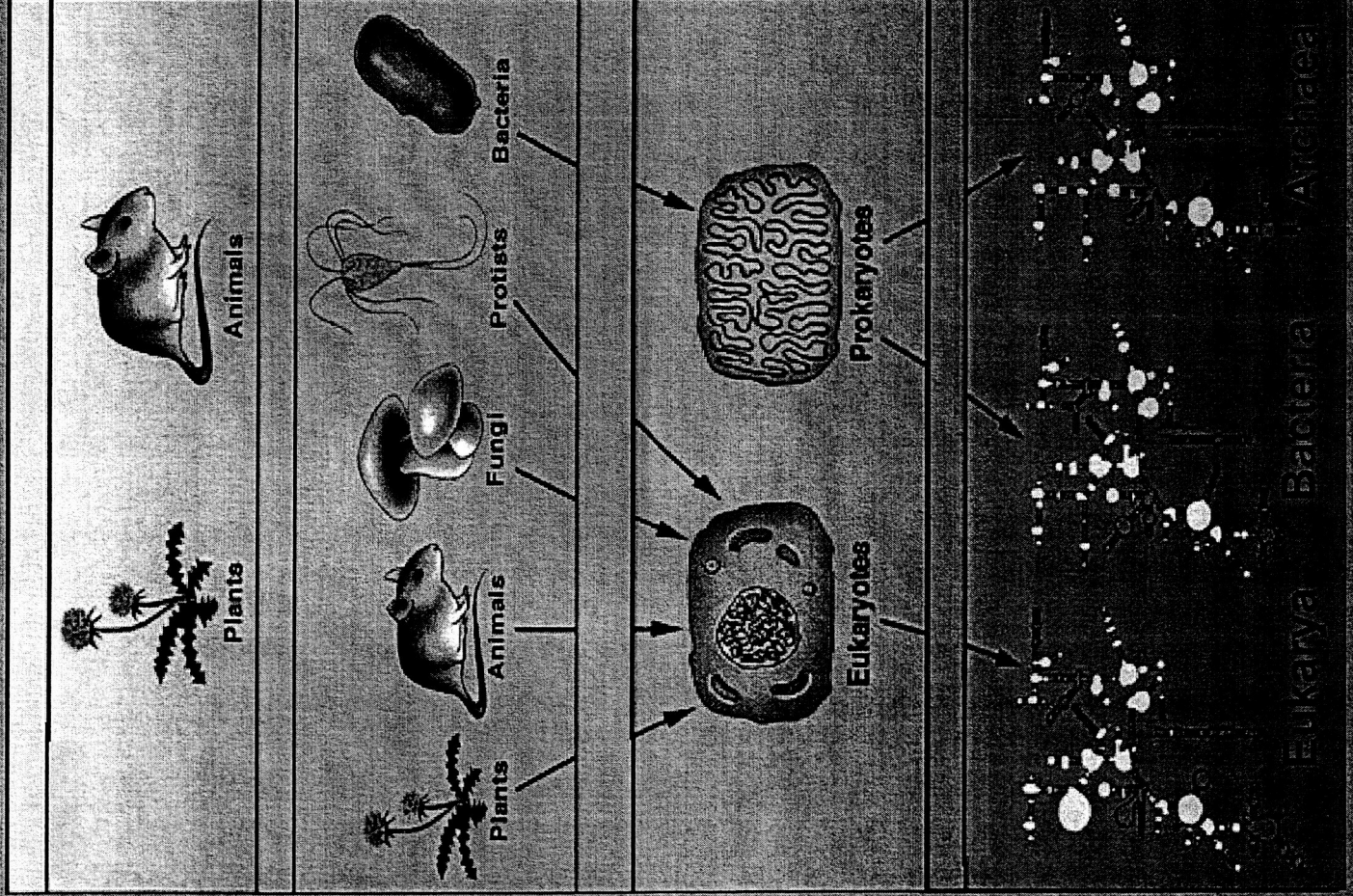
# bacteria

# Eukarya





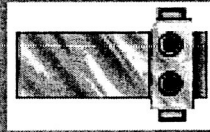
# Observation



# Microscopy

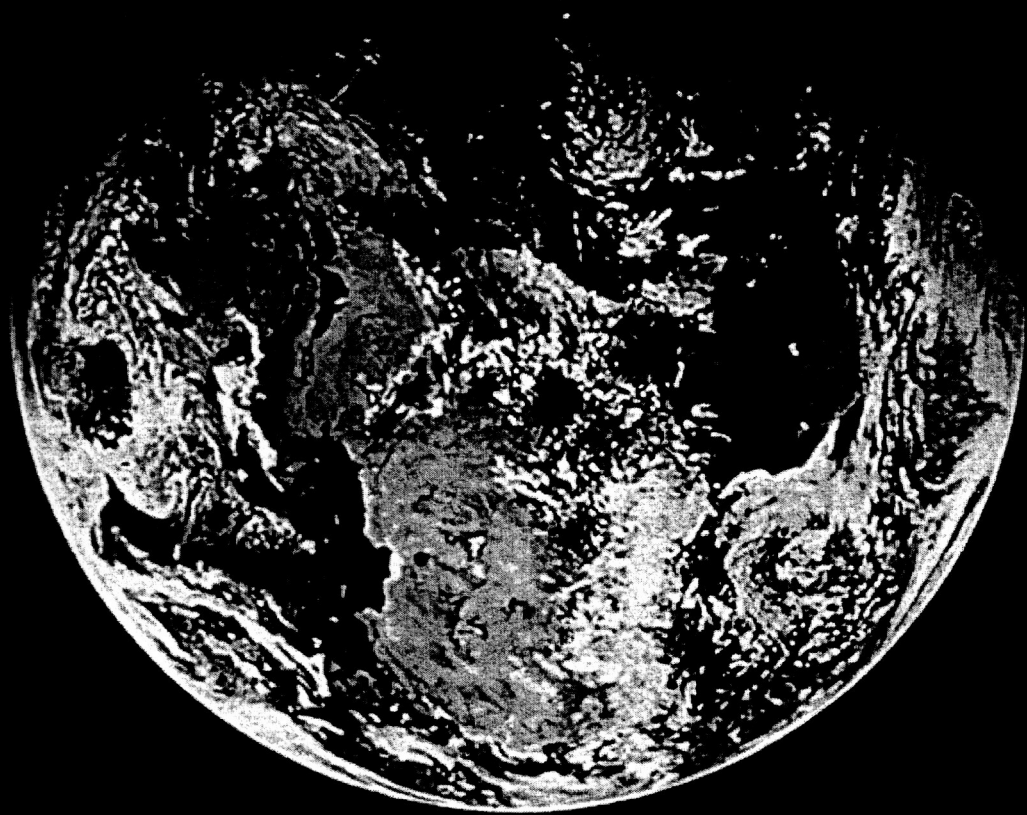


# Modern Microscopy



# Molecular Phylogeny



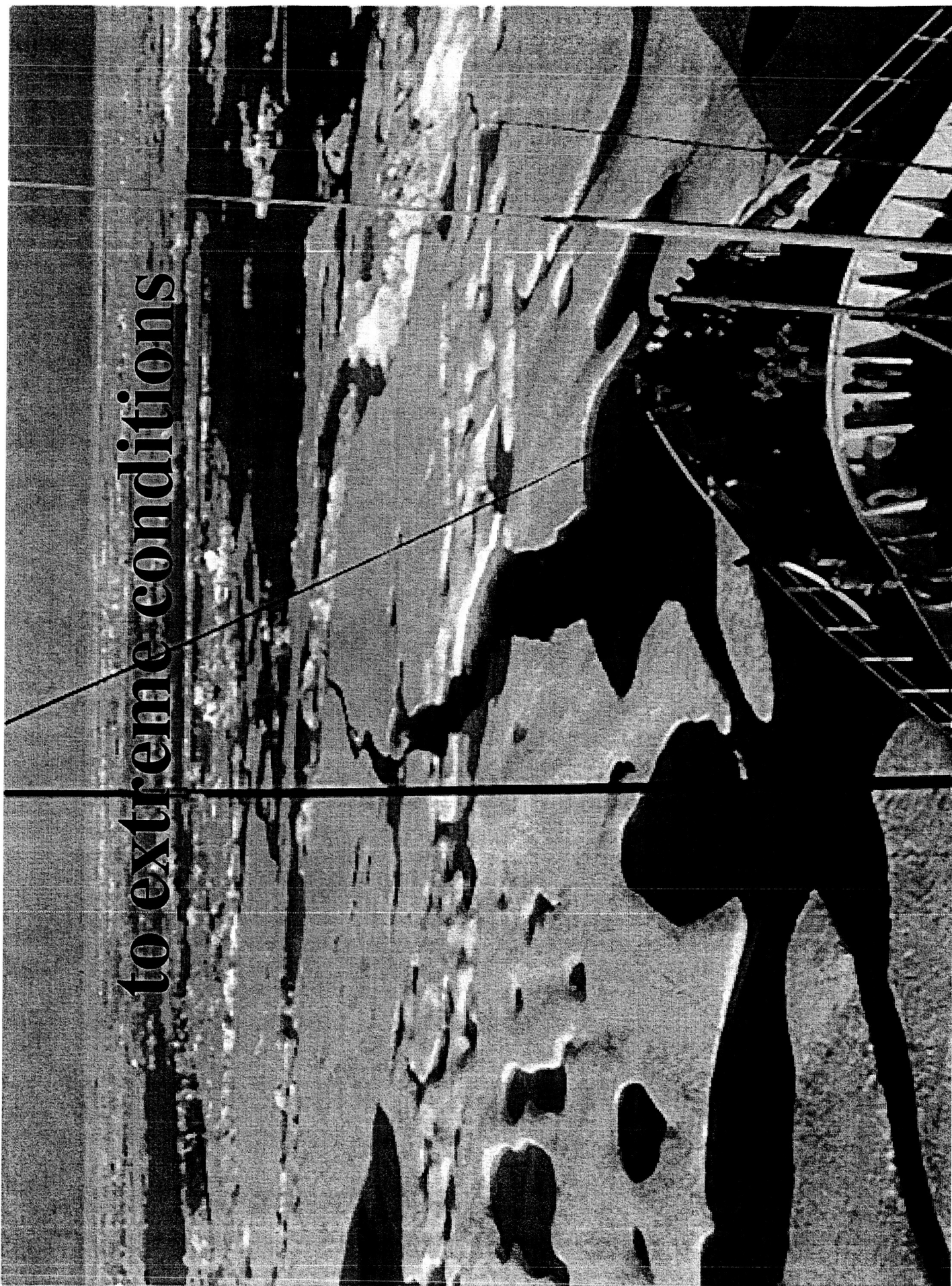




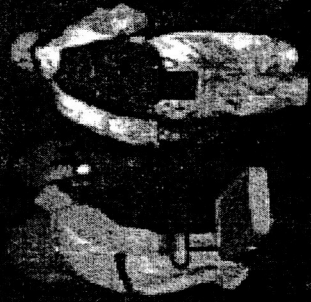
# Diversity and Adaptability



to extreme conditions



# Unexpected environments



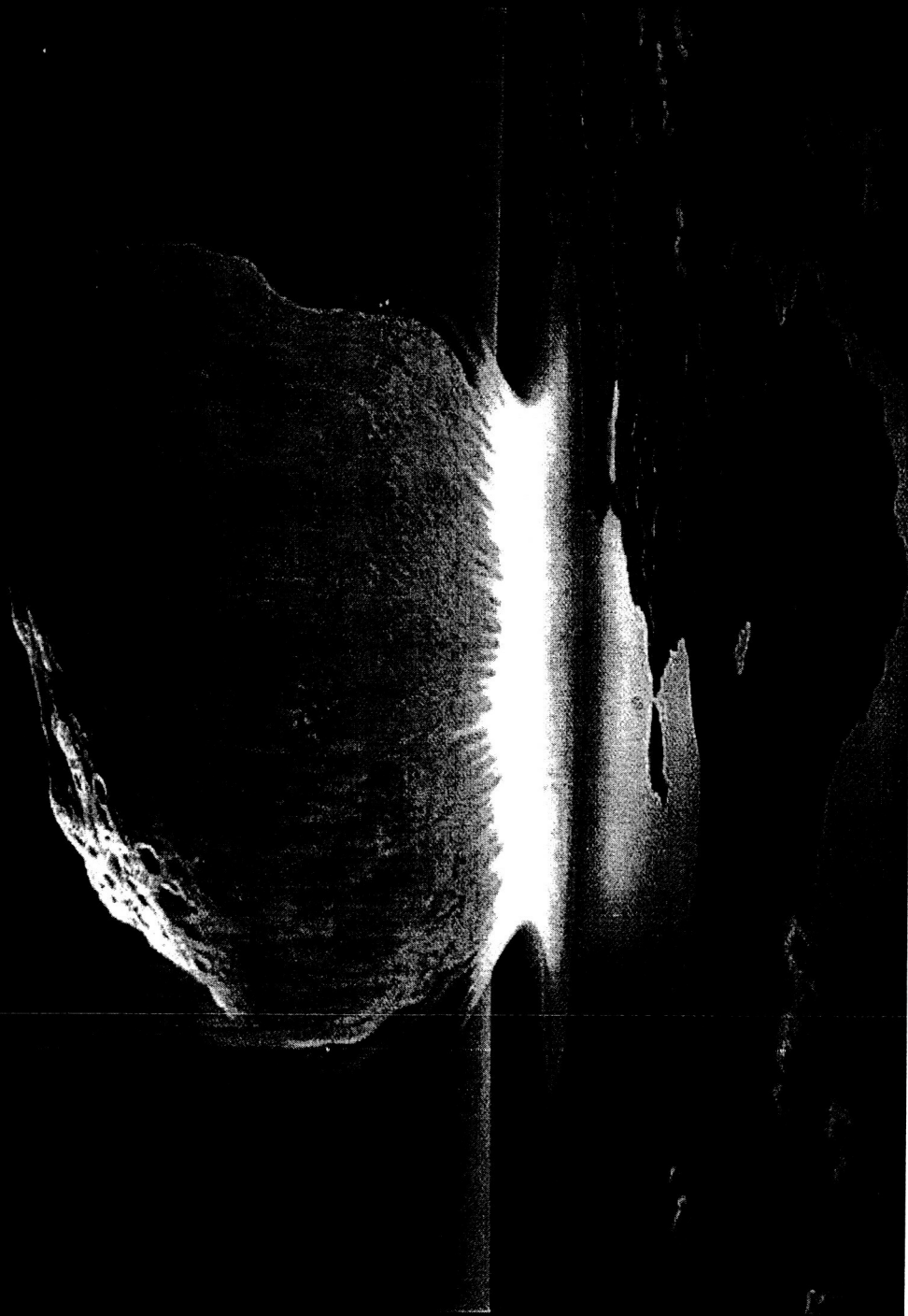


**Unfathomable abundance and diversity...**

**Abyss**

**1,100 bars pressure**

Remarkable tenacity...



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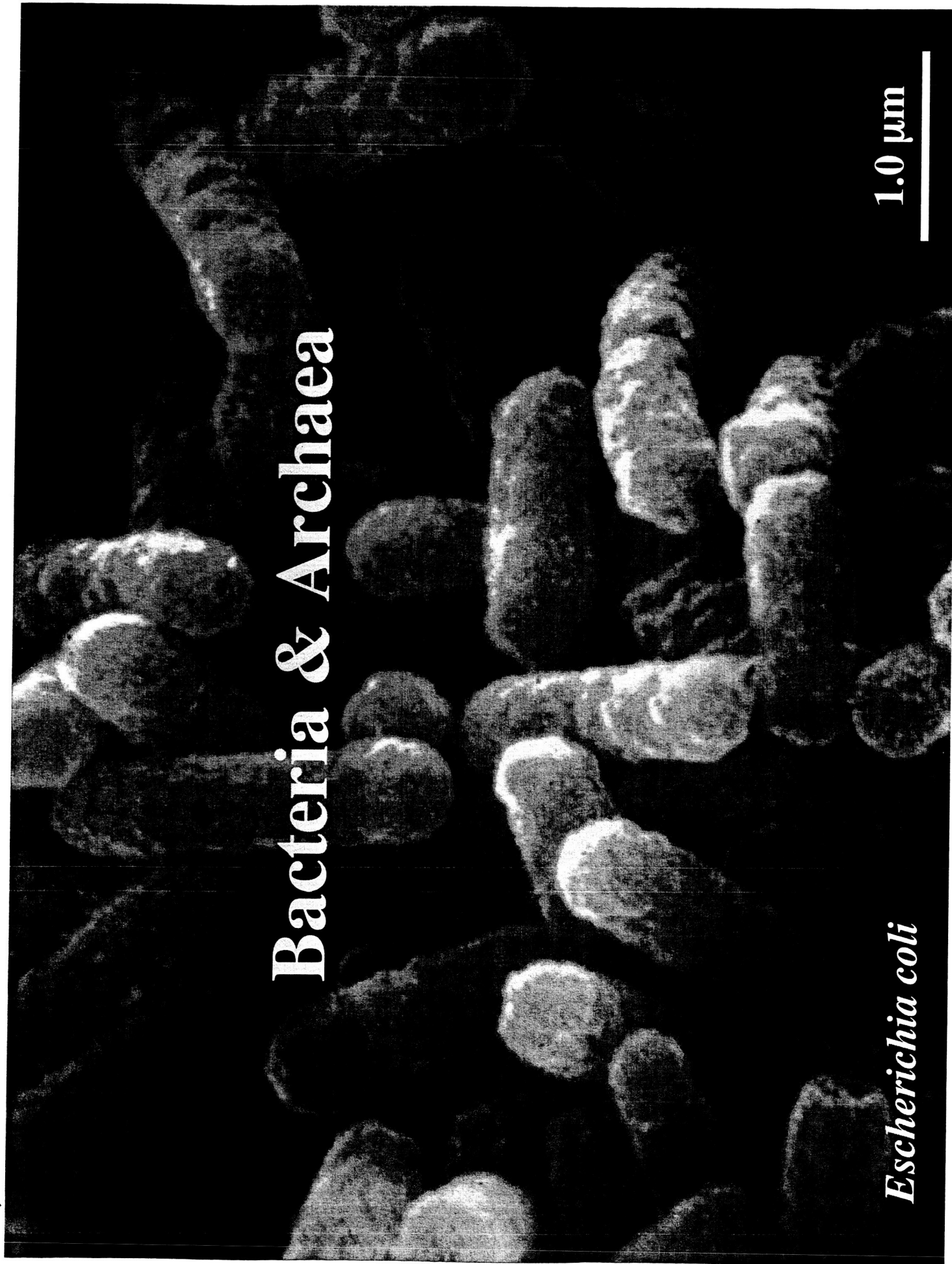
*What are the most efficient and successful  
biomolecular machines?*

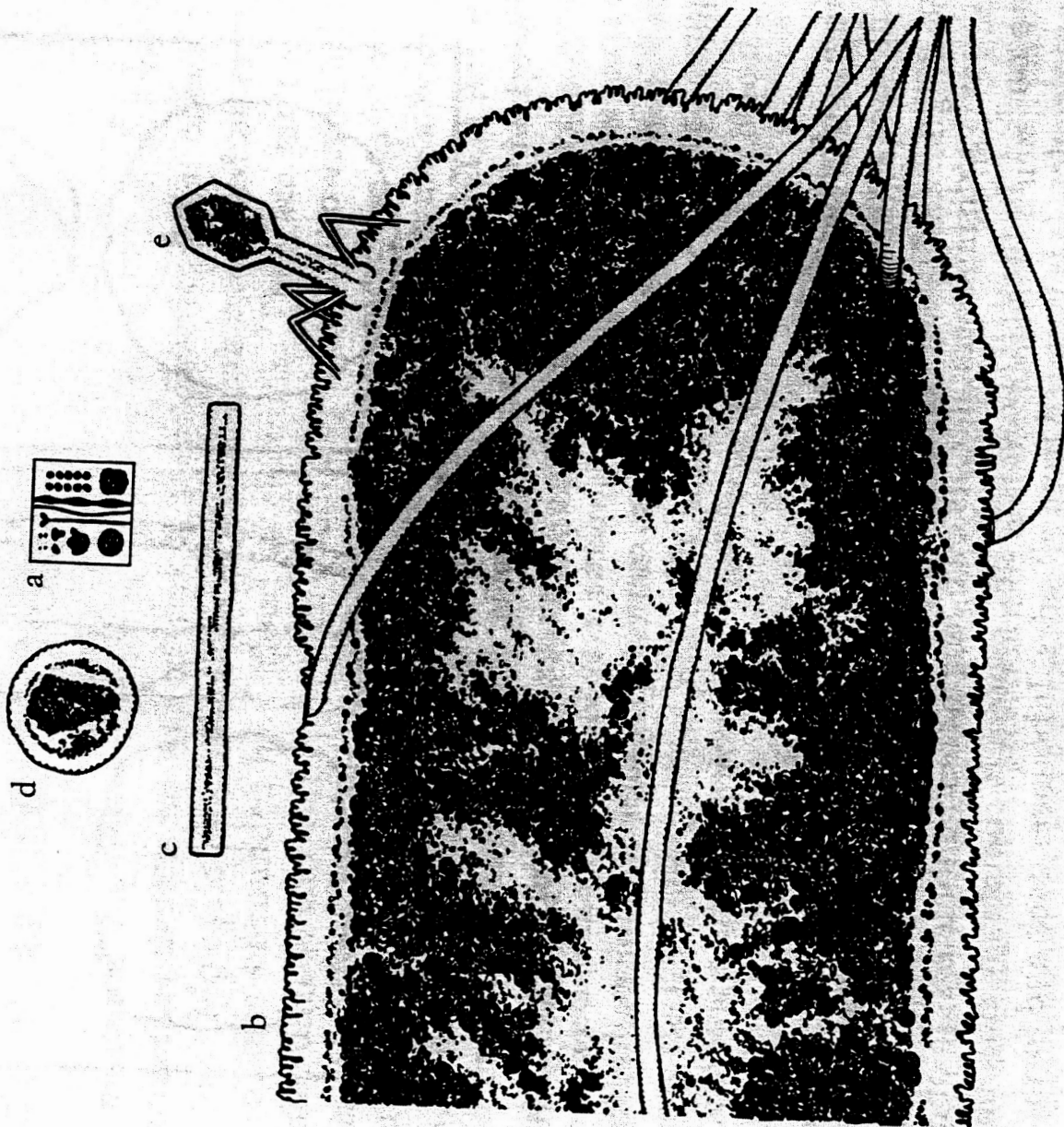
*Self-replicate in 20 min  
Sense and respond to their environment  
Adapt to a variety of harsh conditions  
Have robust and dynamic structures*

# Bacteria & Archaea

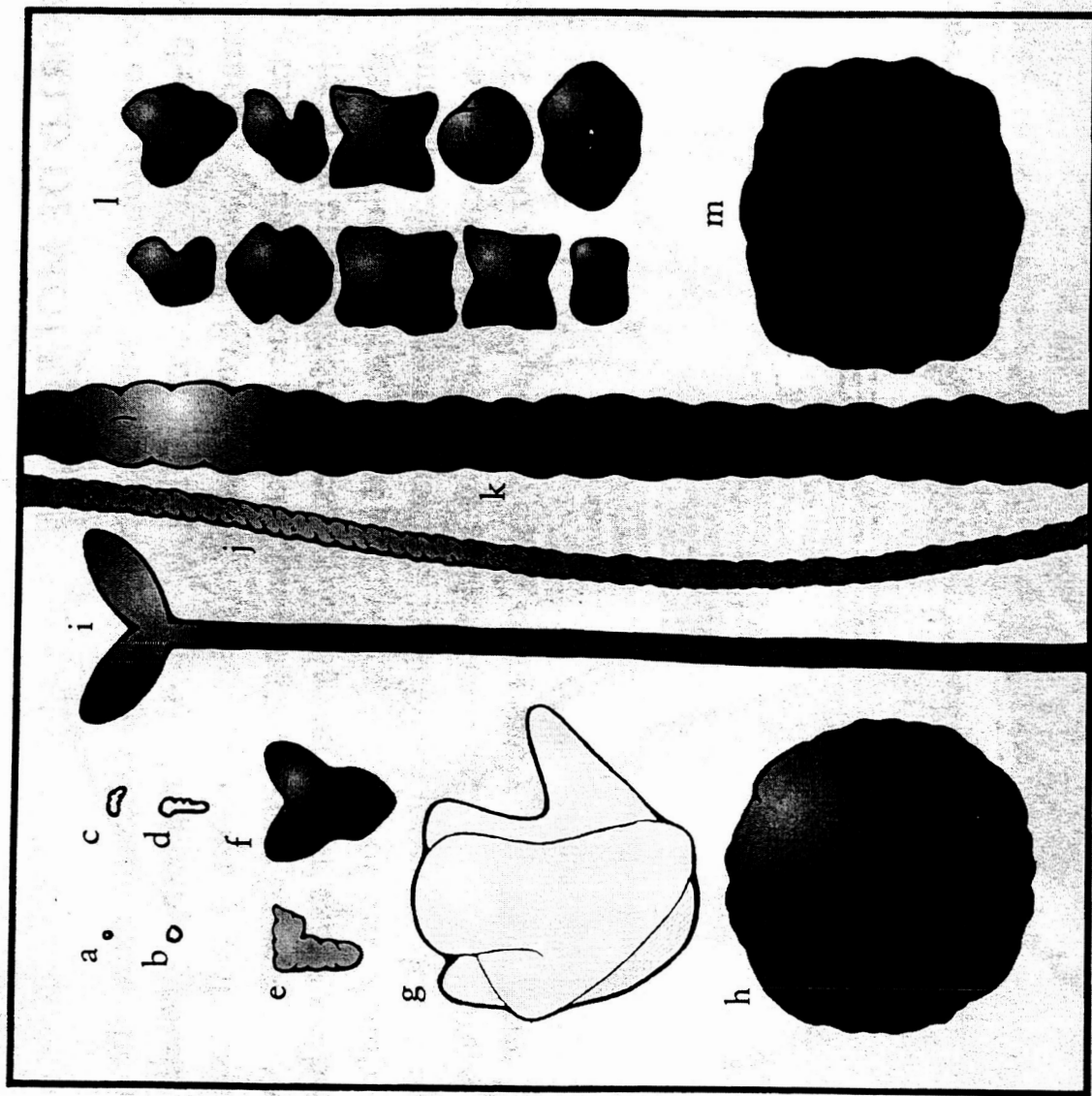
*Escherichia coli*

1.0  $\mu\text{m}$



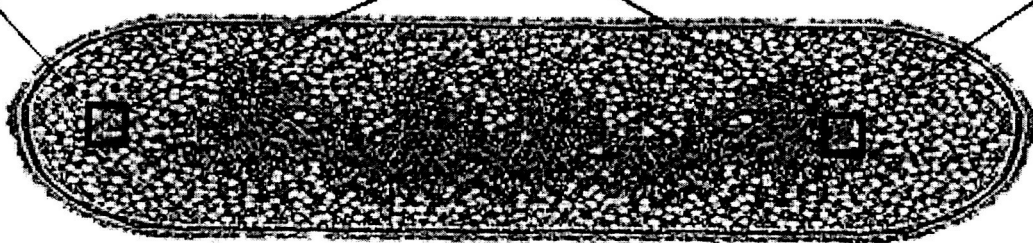
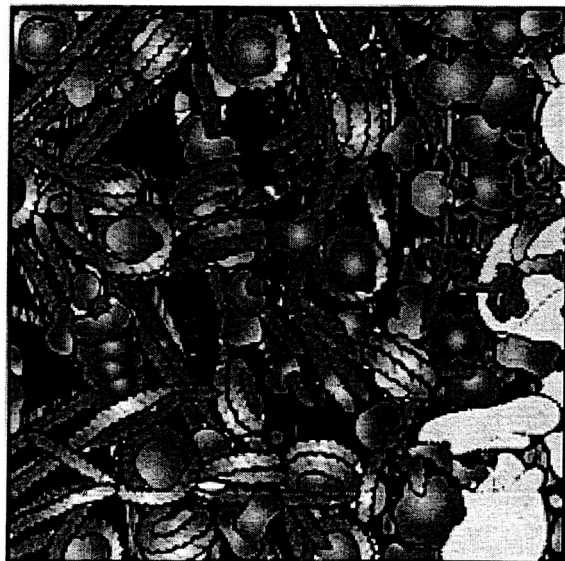
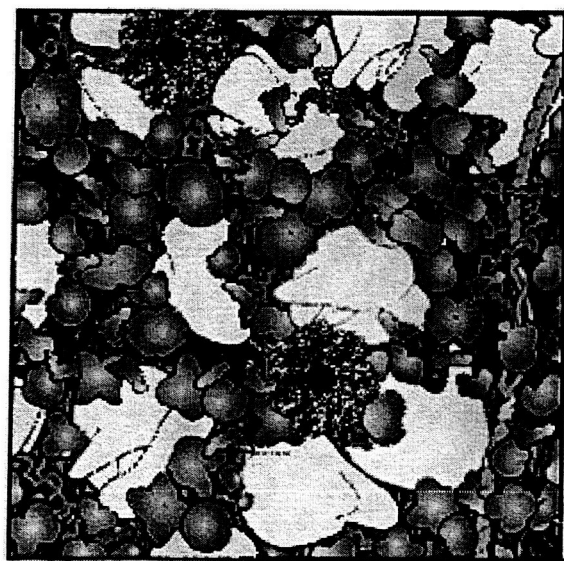


0.5  $\mu\text{m}$



0.05  $\mu\text{m}$

50 nm

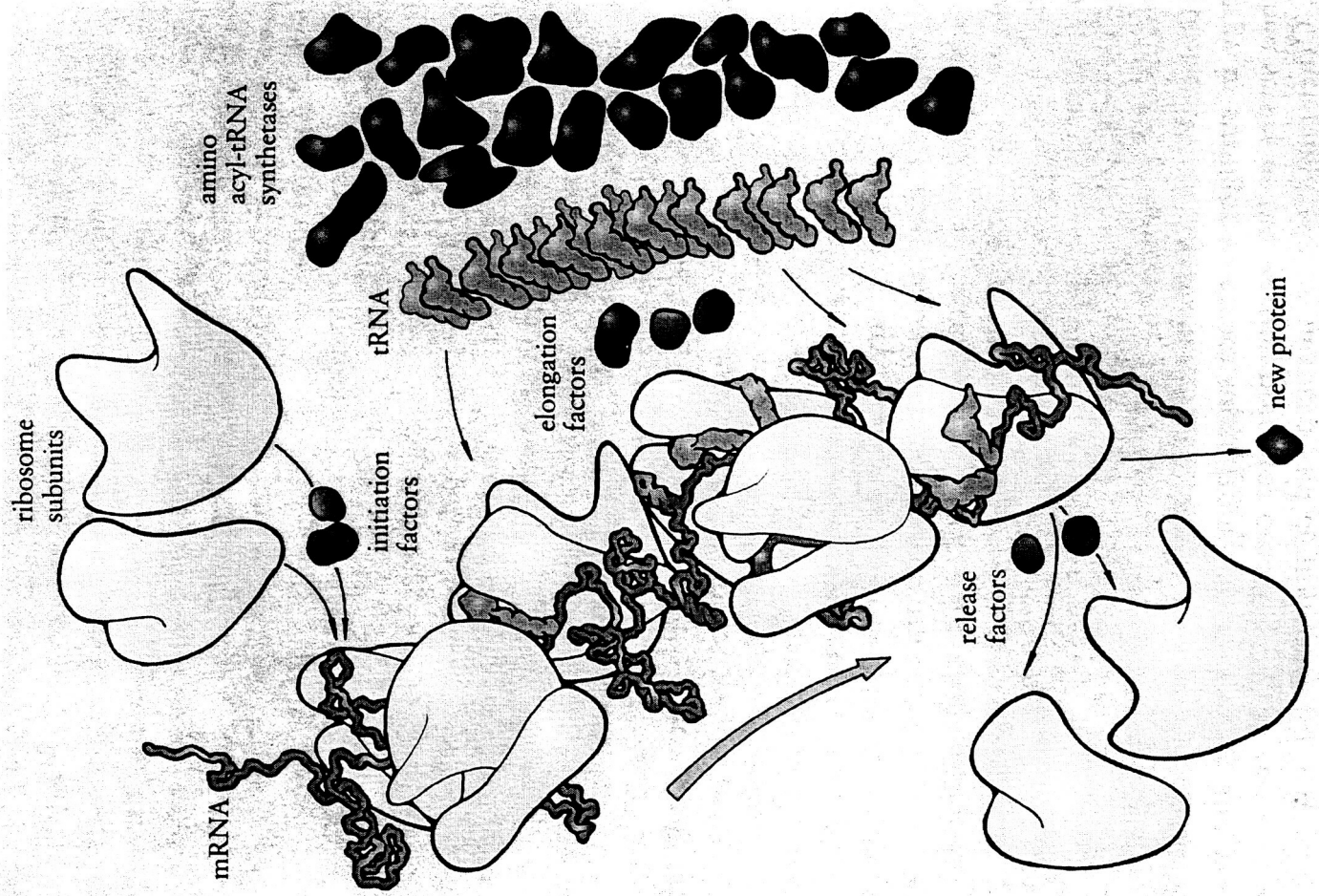


1  $\mu$ m

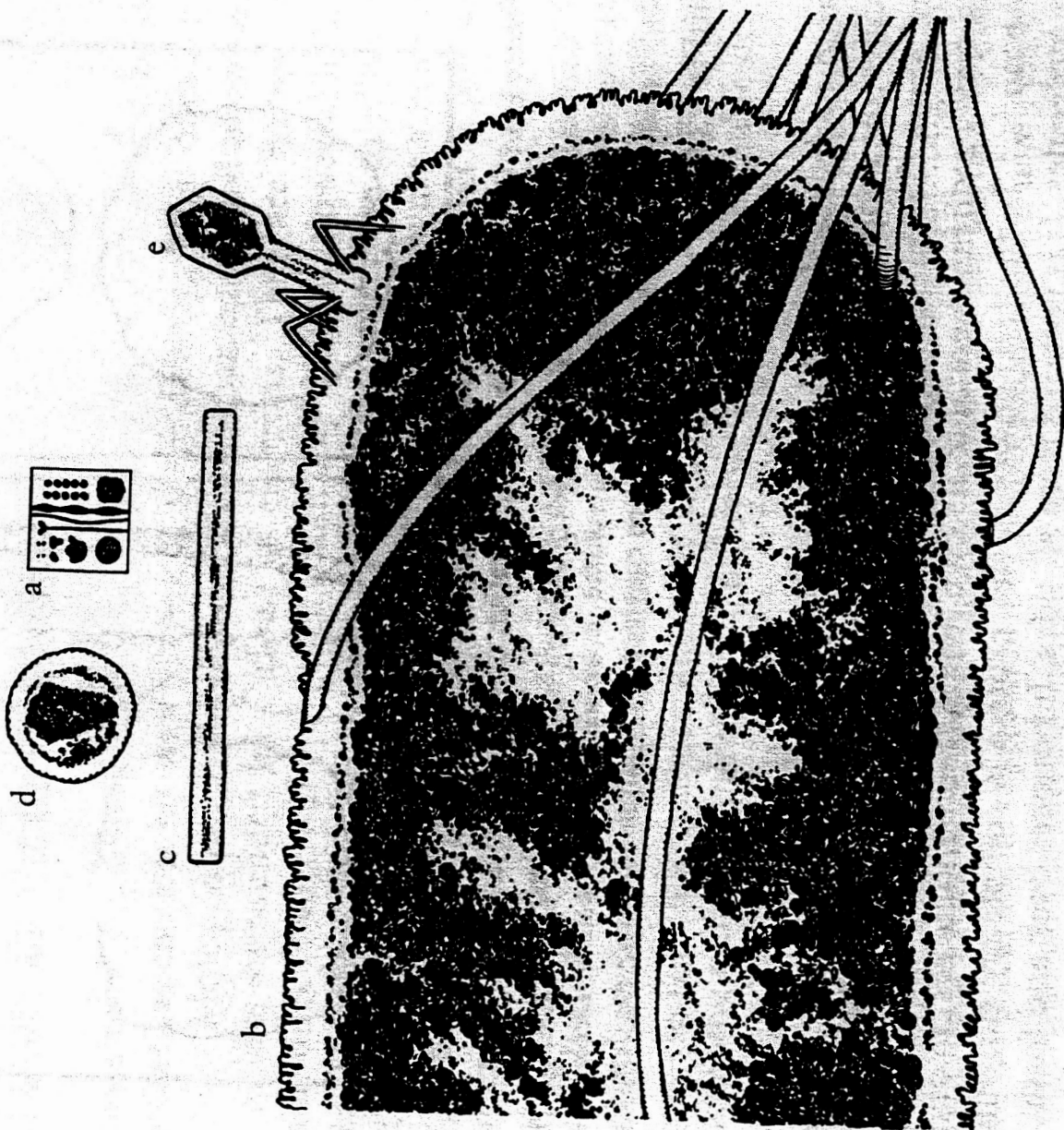
50 nm

From Goodsell

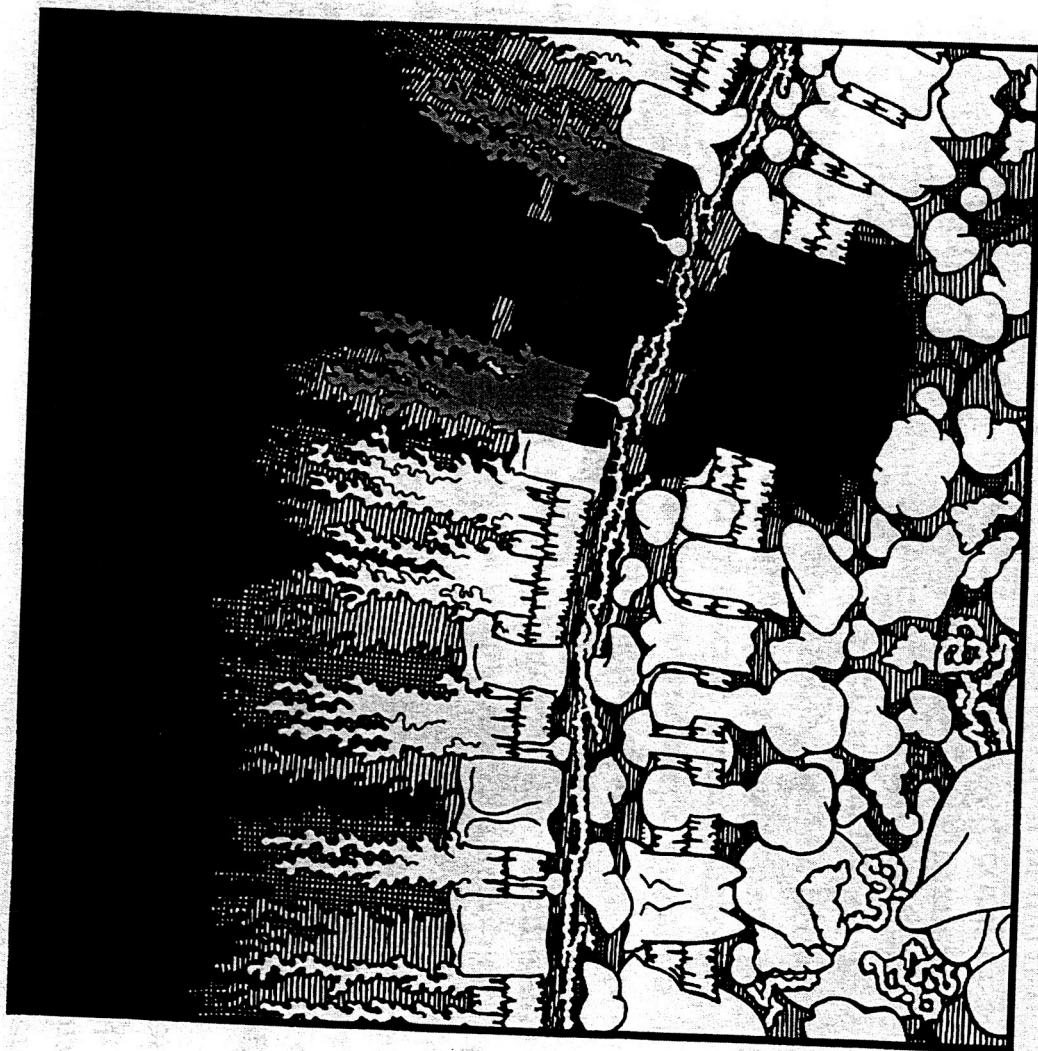








0.5  $\mu\text{m}$



**Propulsion speed?**

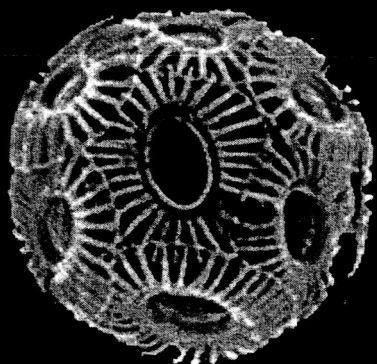
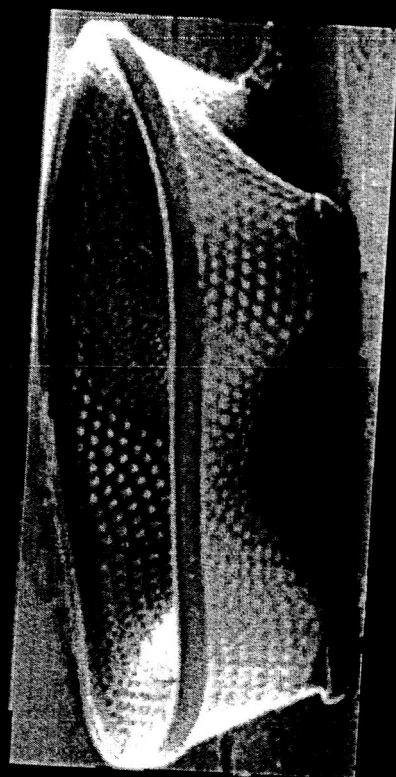


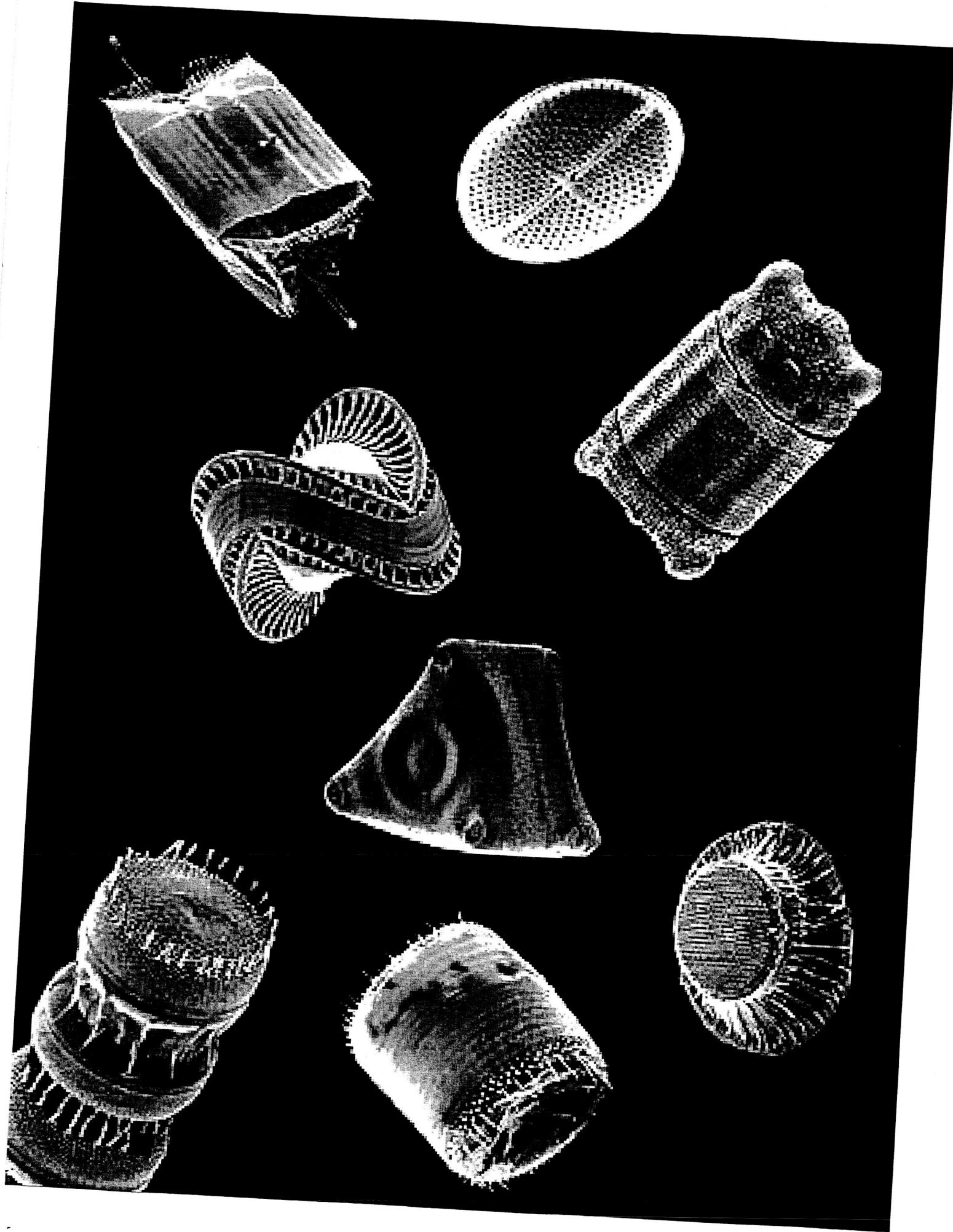
# Bio-Molecular-Engineering

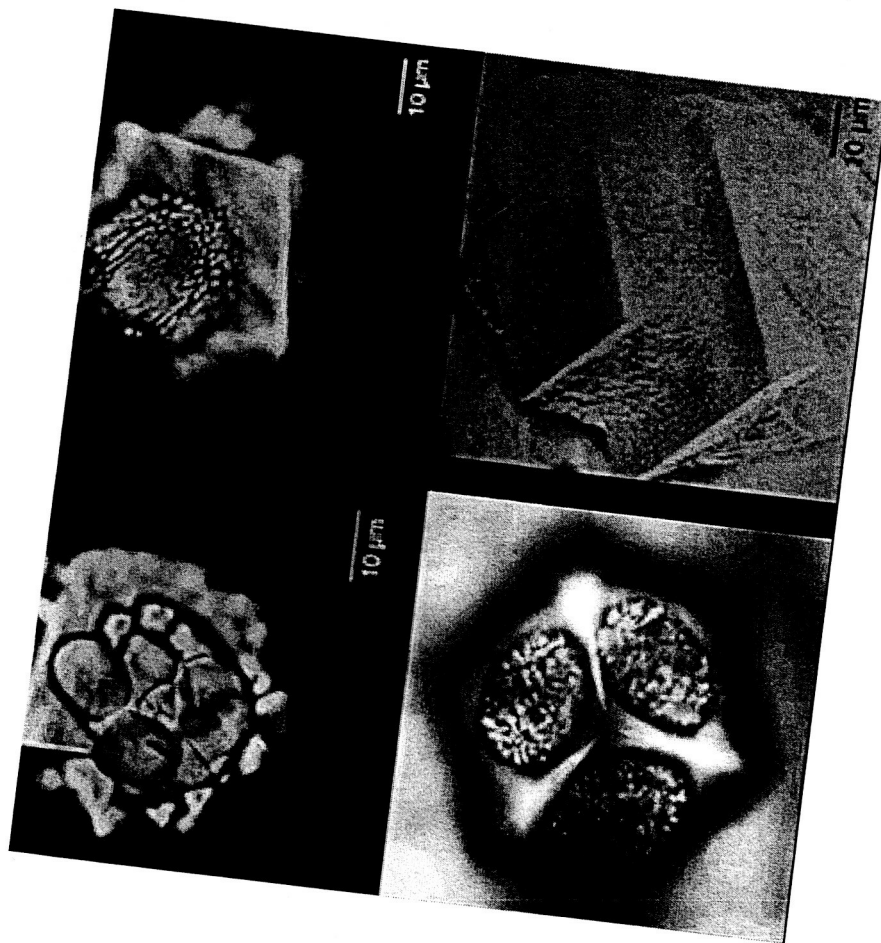
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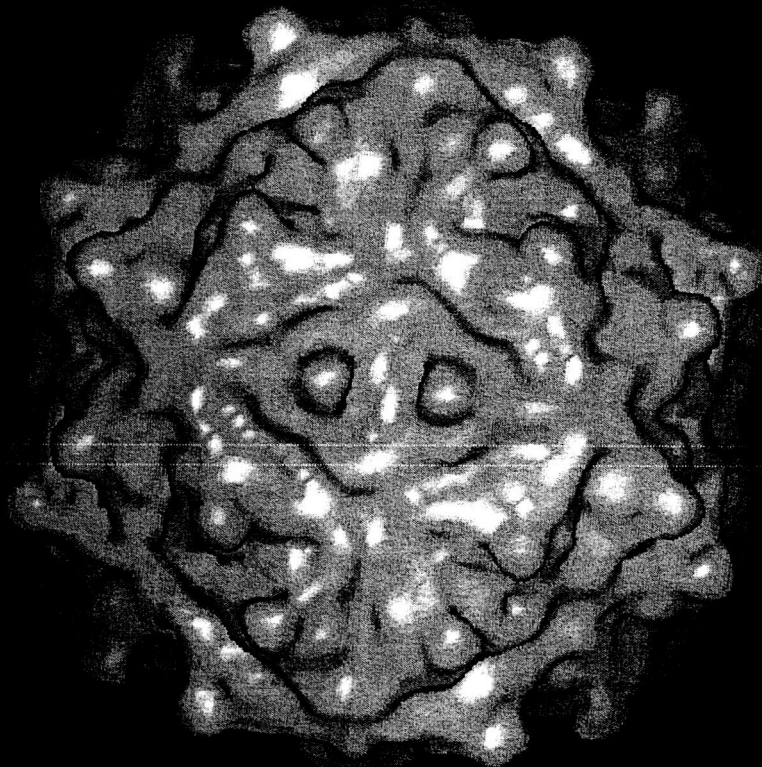
*Nano bio-materials and  
Nano bio-tools?*



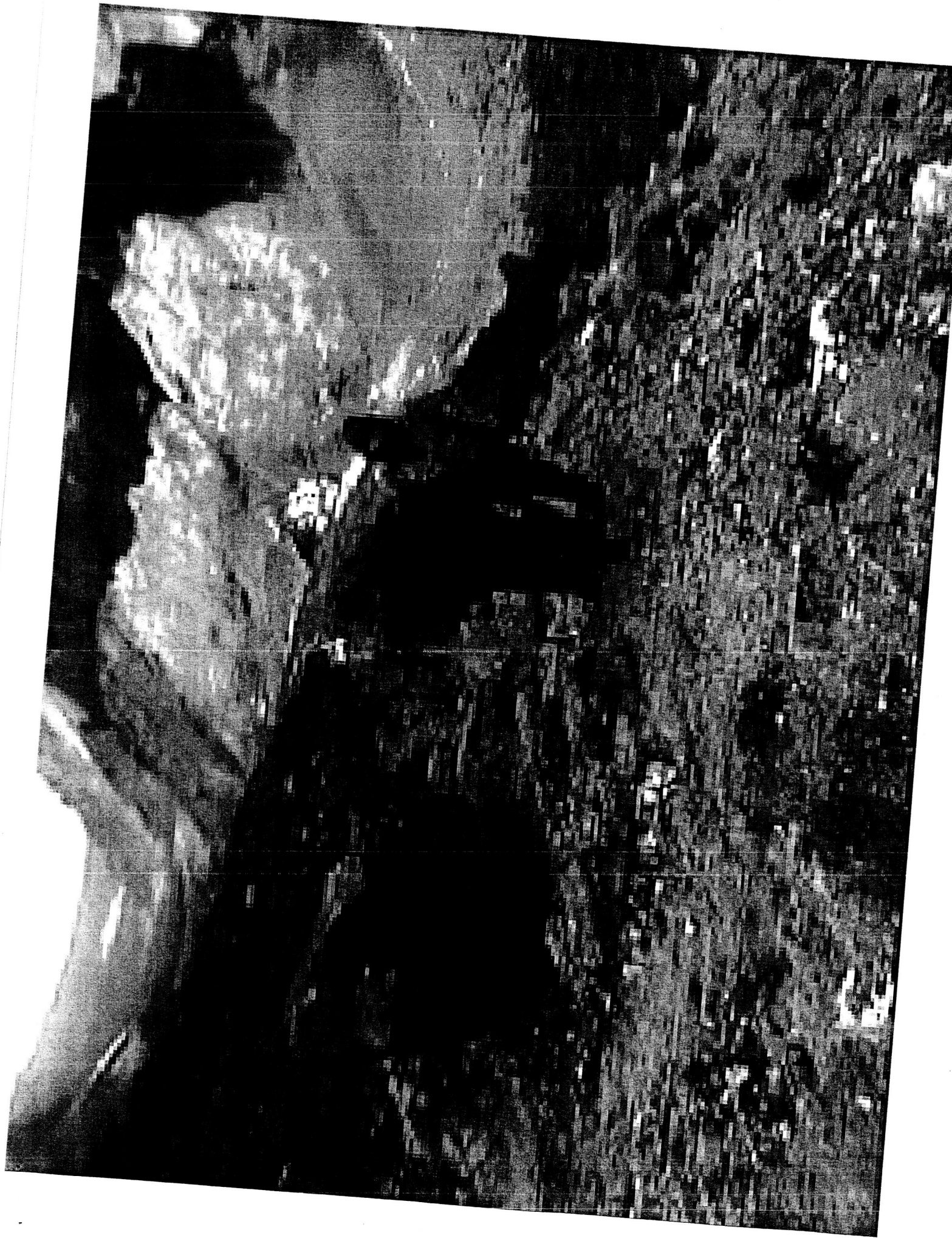




# Proteins as scaffolds for mineralization

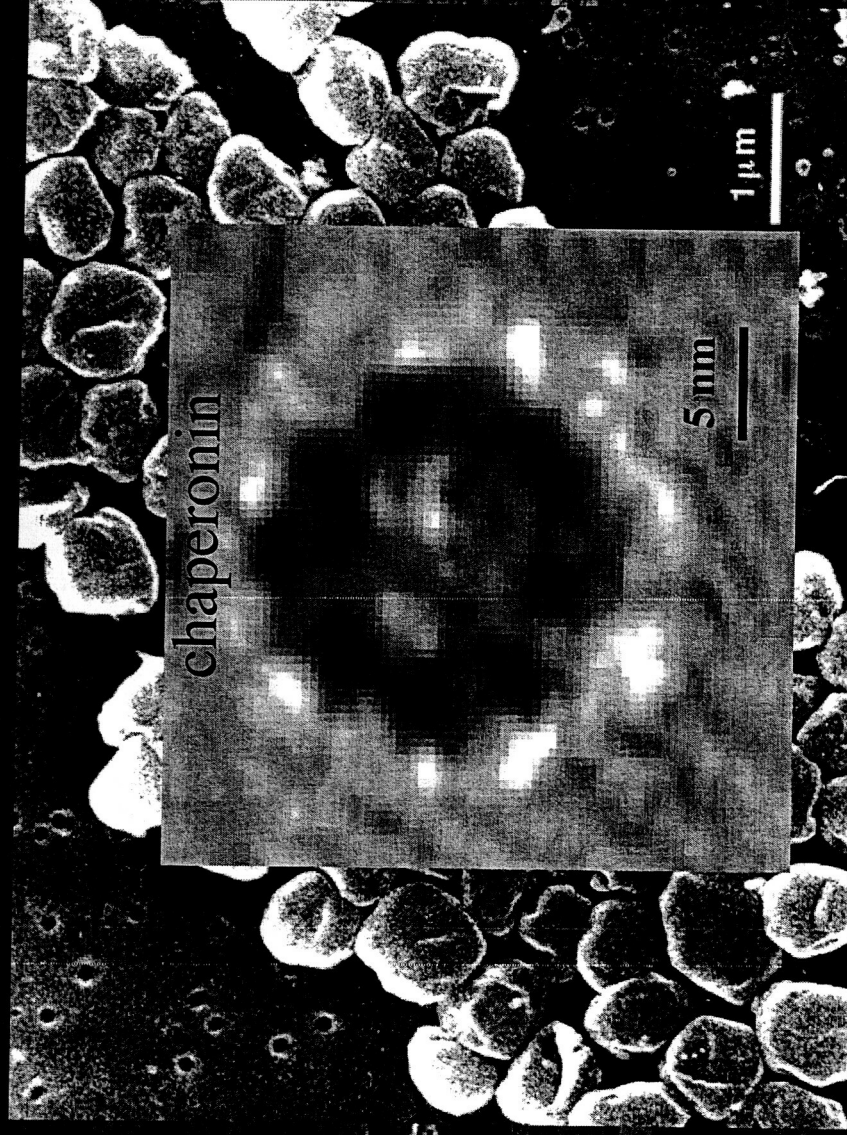








Thermophile: *Sulfolobus shibatae*



85°C/pH 2.0

# Why use proteins from a thermophile?

Transfer gene  
to *E. coli*

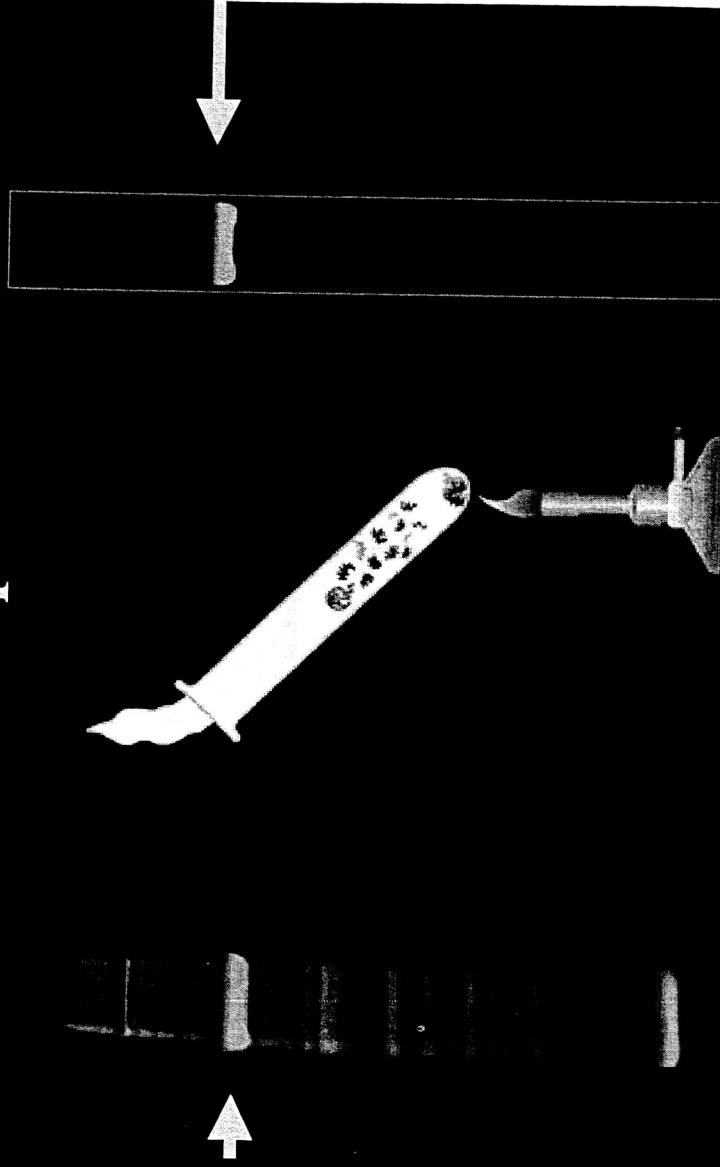
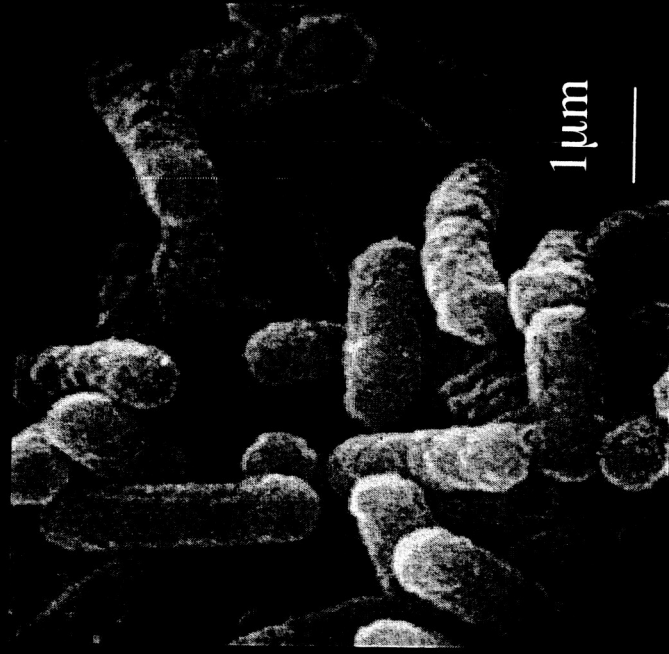
Extract  
proteins

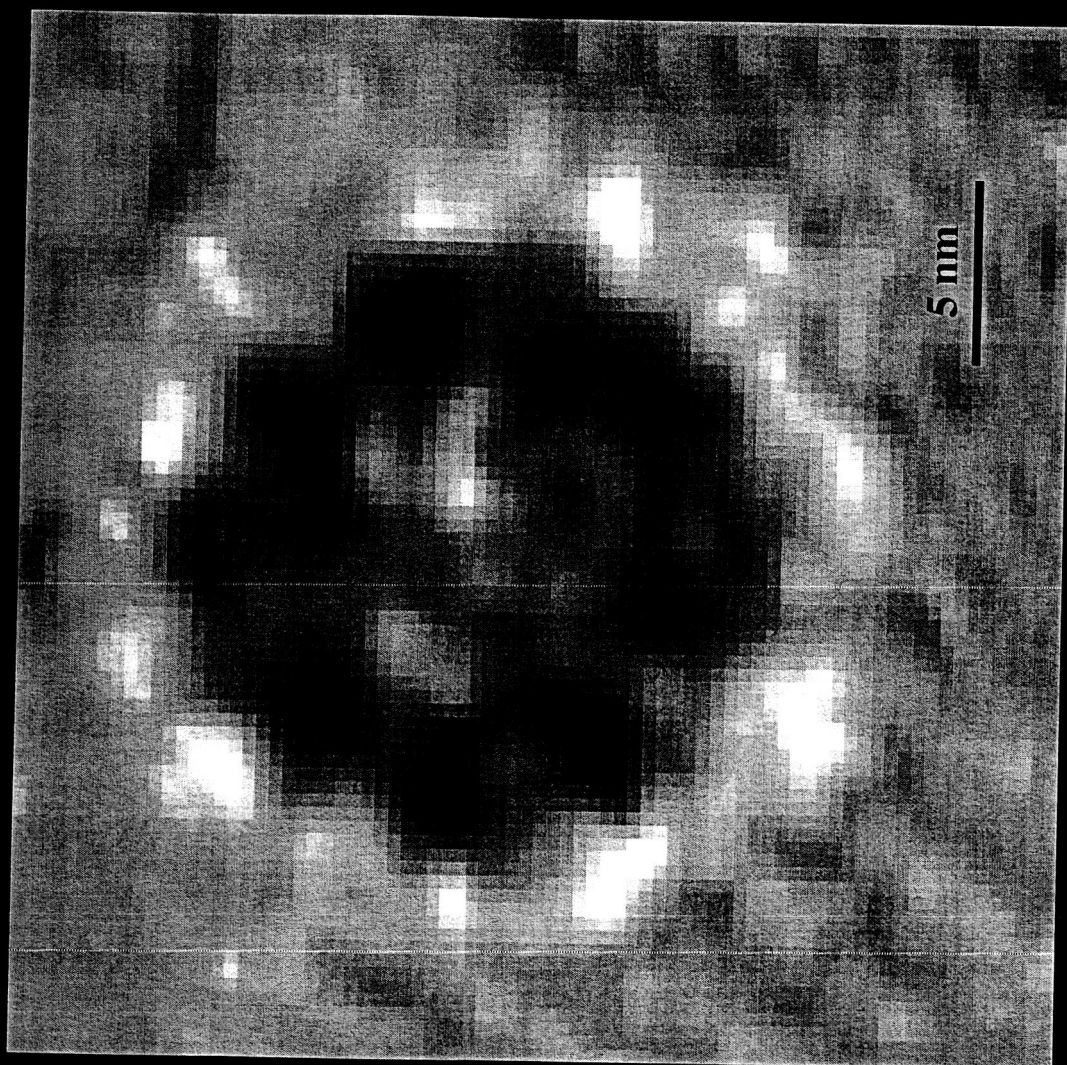
+

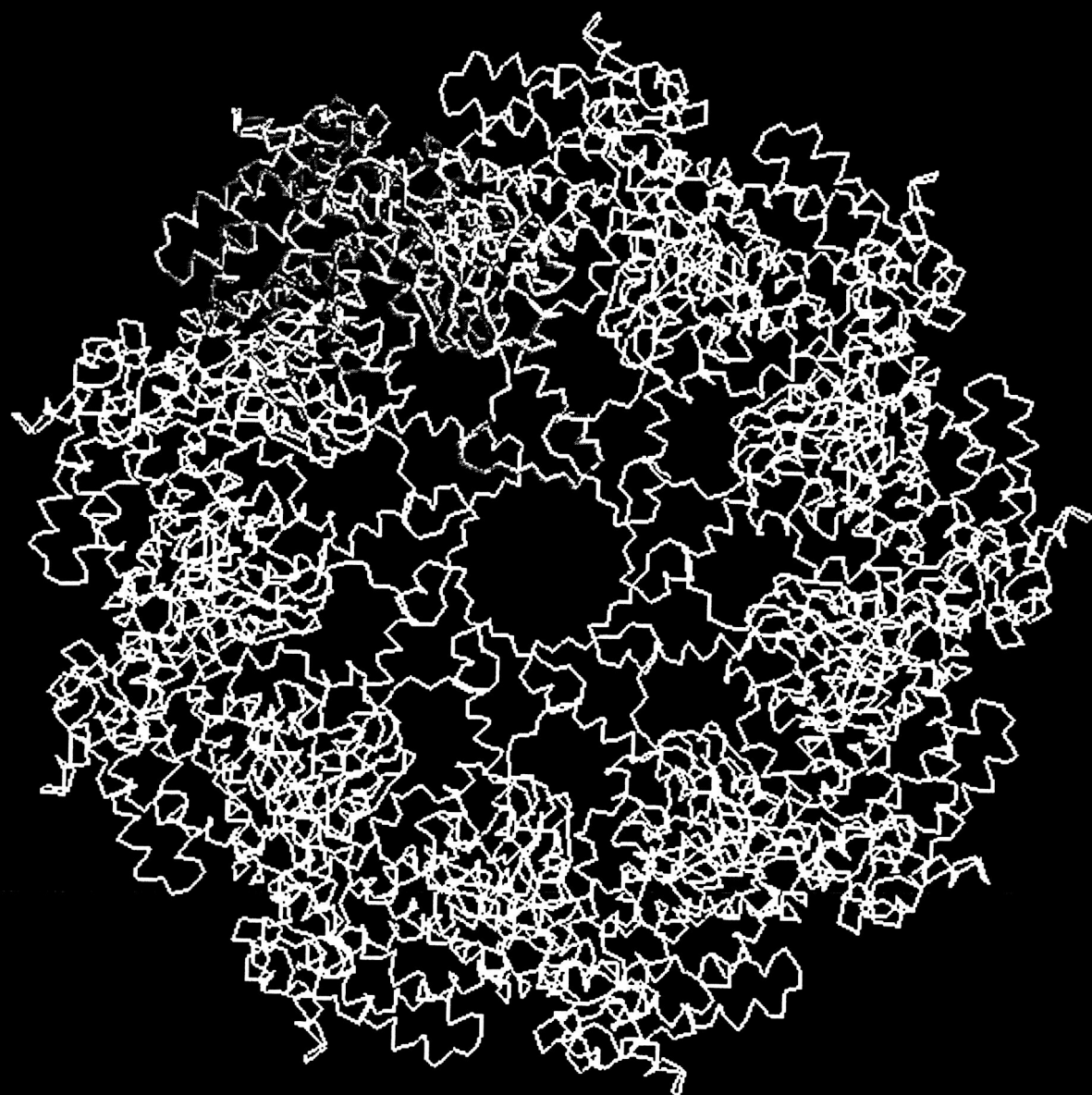
Heat  
/spin

=

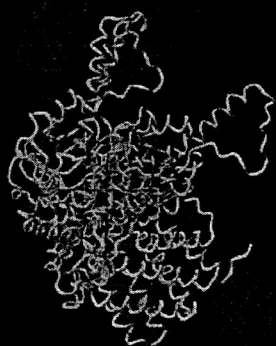
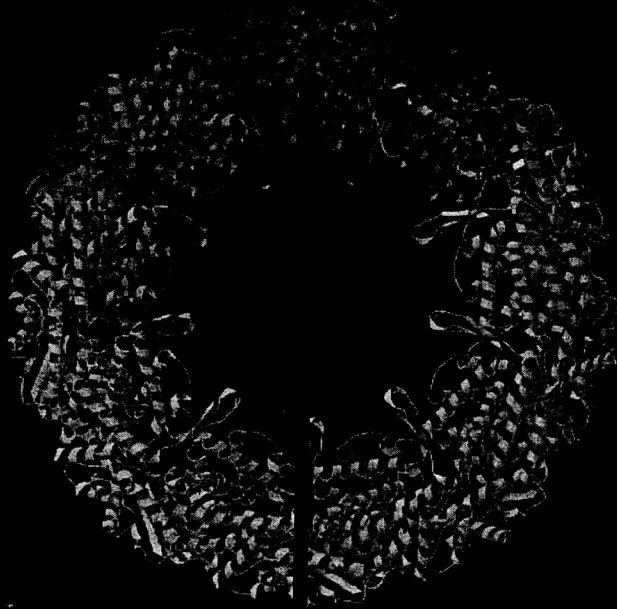
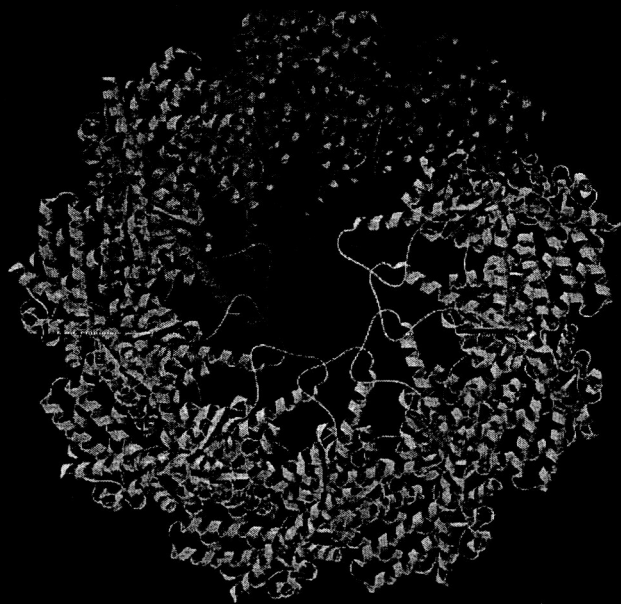
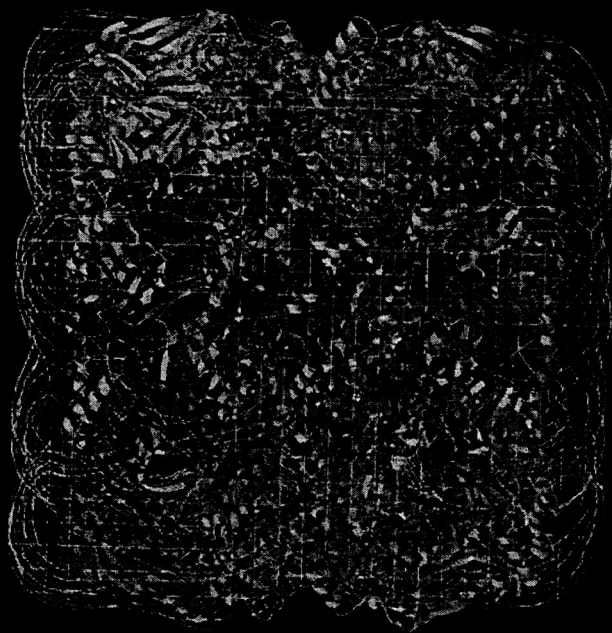
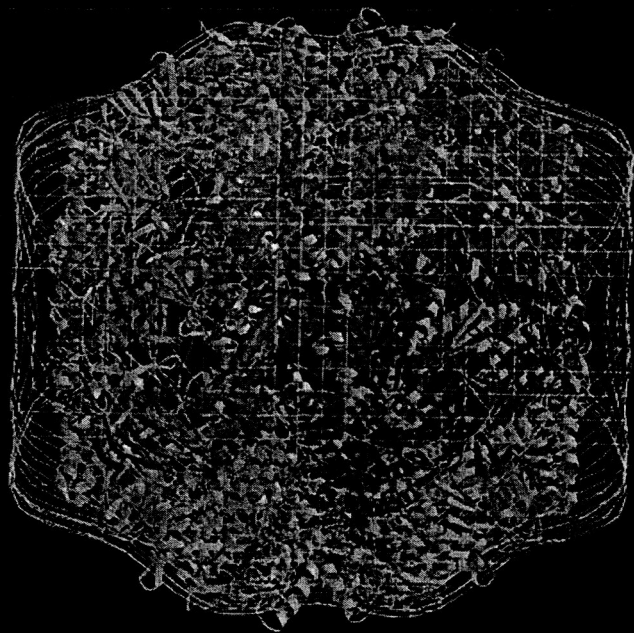
Protein  
product

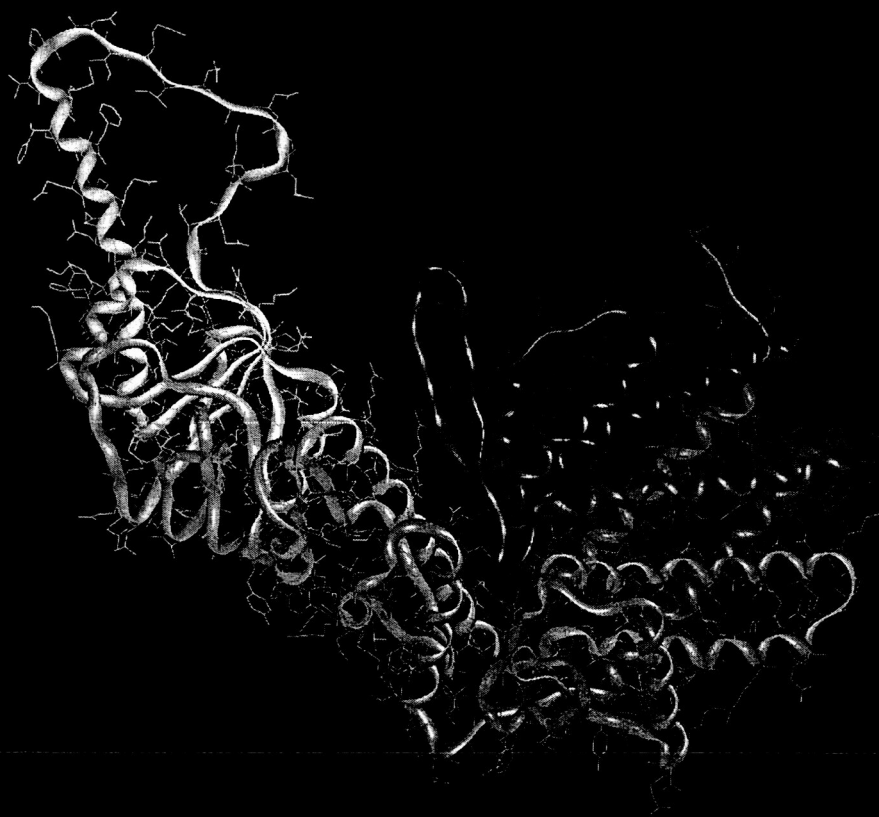


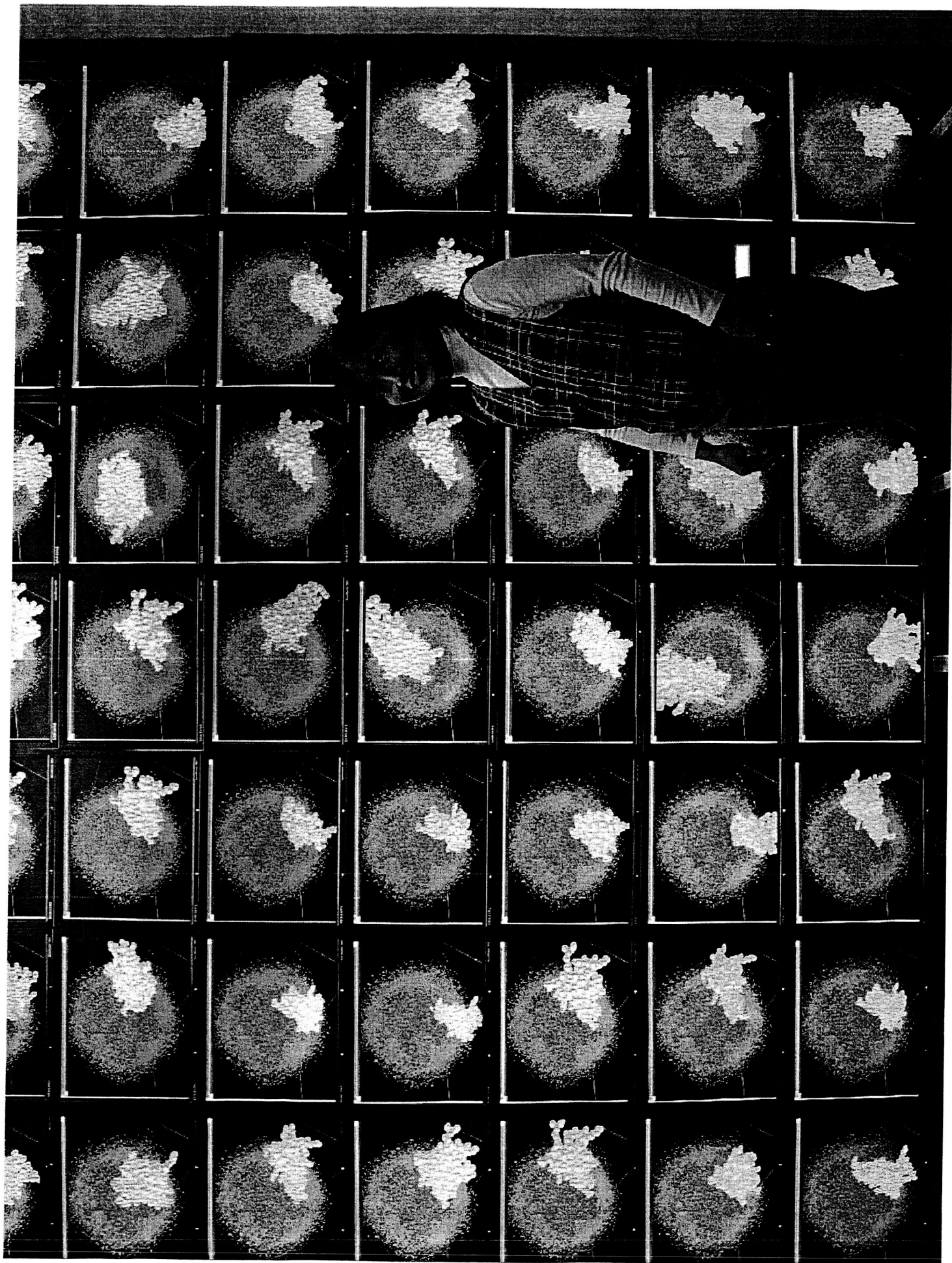






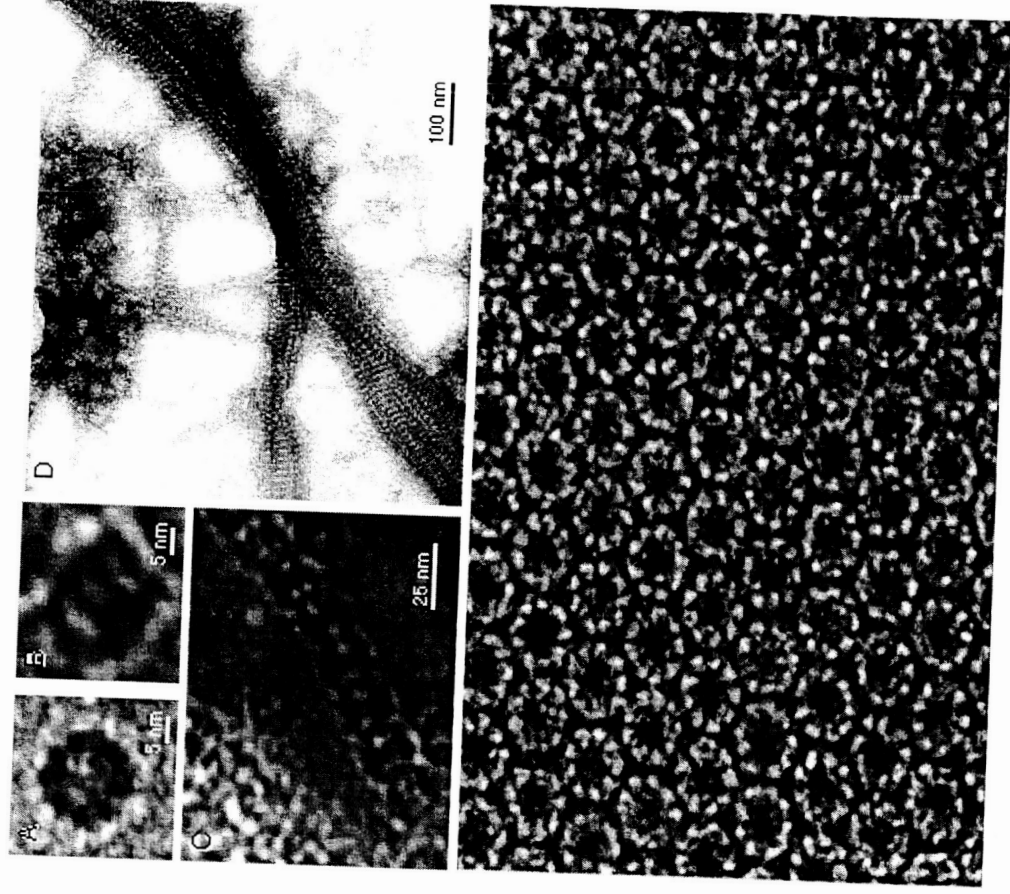






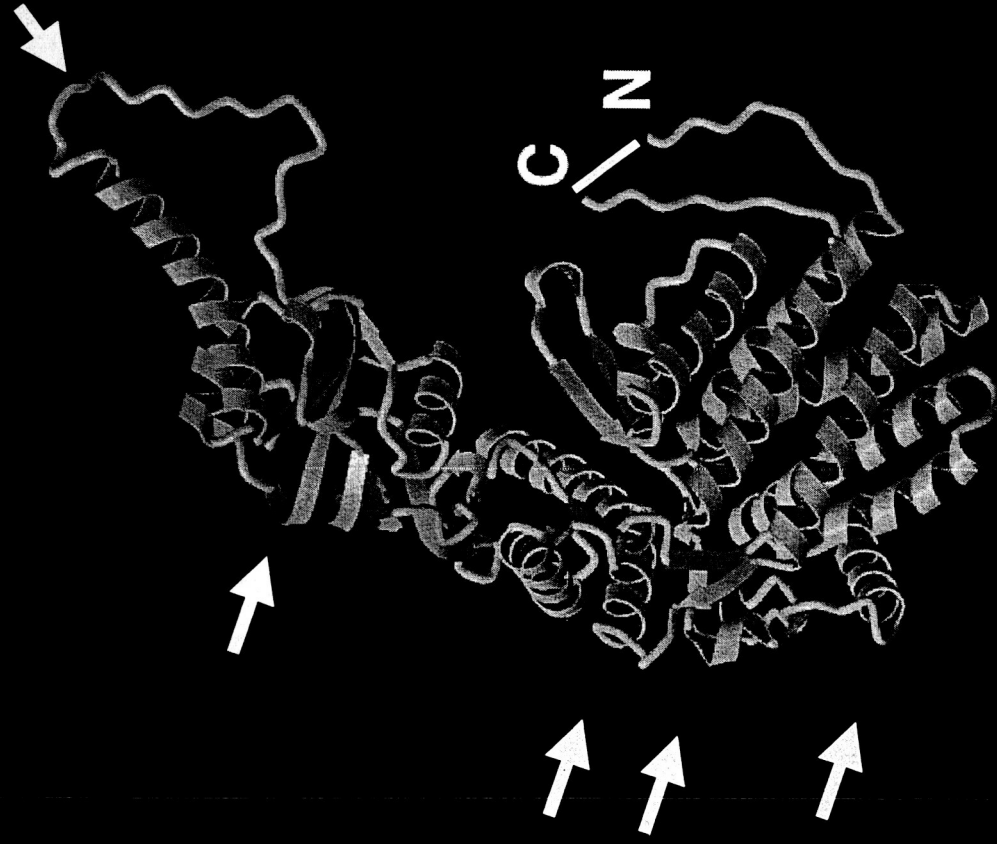
## *Chaperonin proteins as nano-tools?*

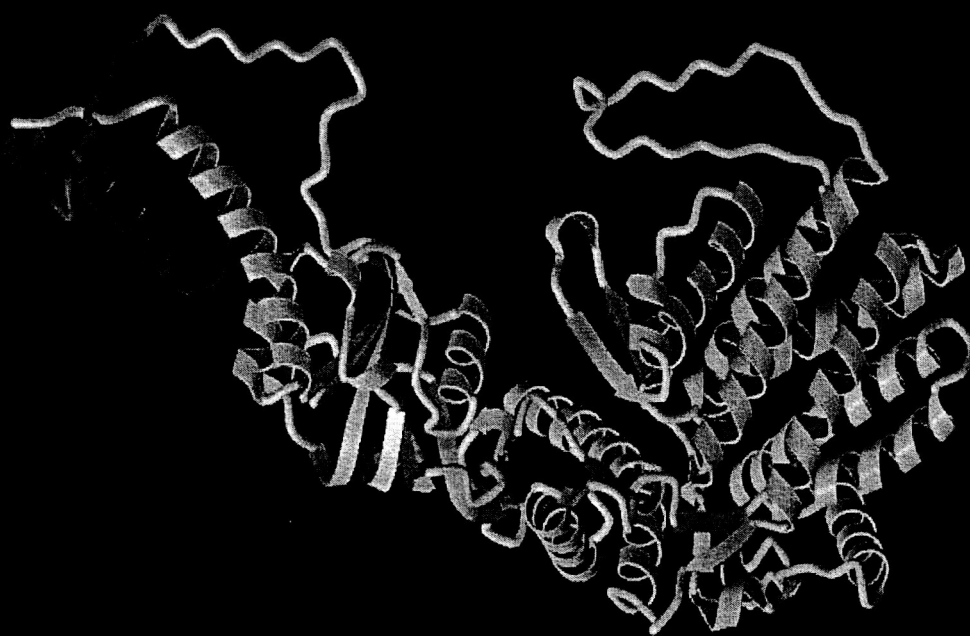
- Templates
- Carriers
- Reaction vessels

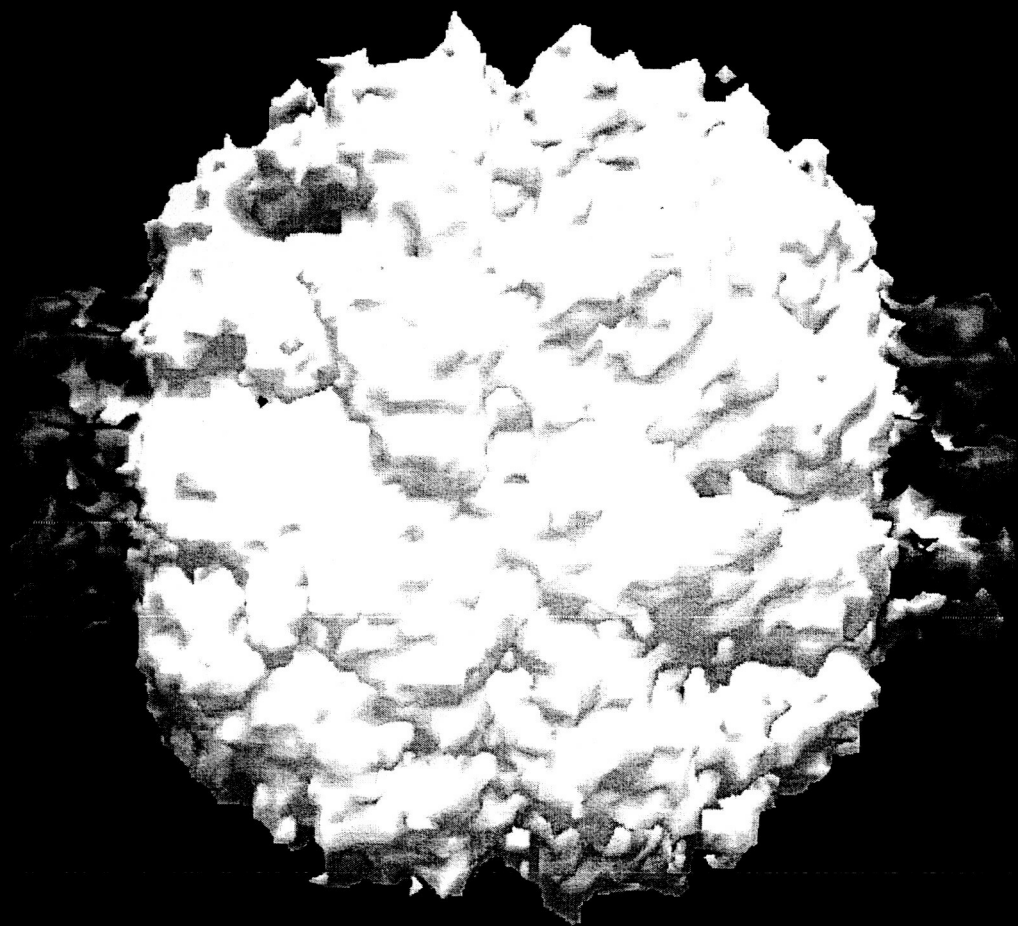


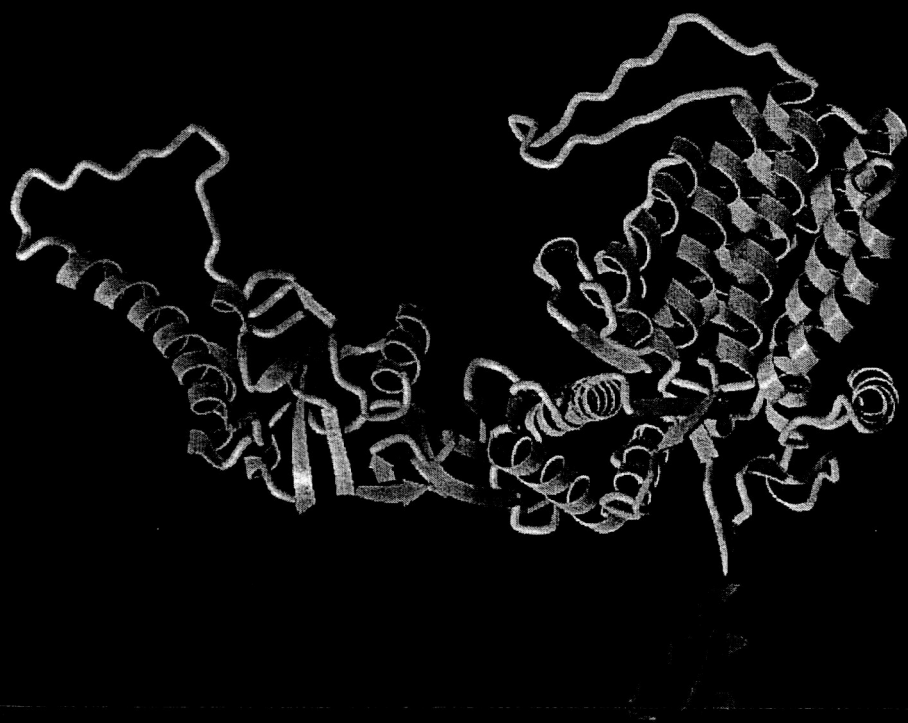


# Redesigning proteins with genetic engineering

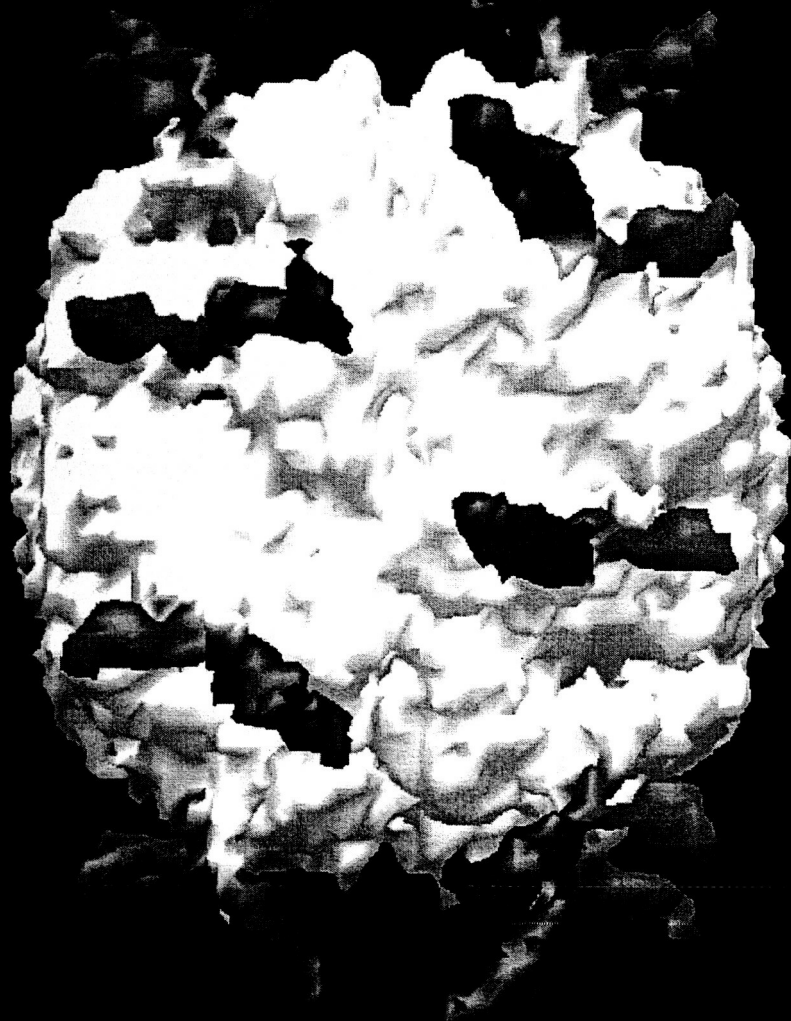


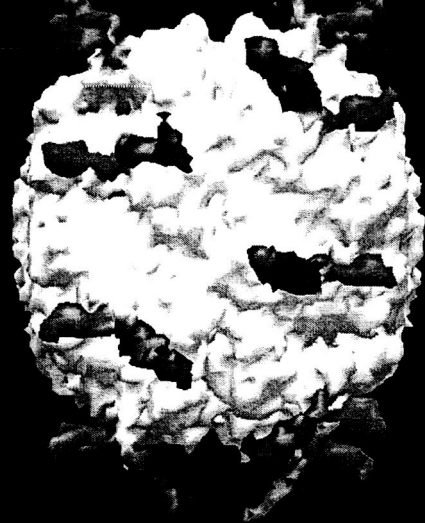
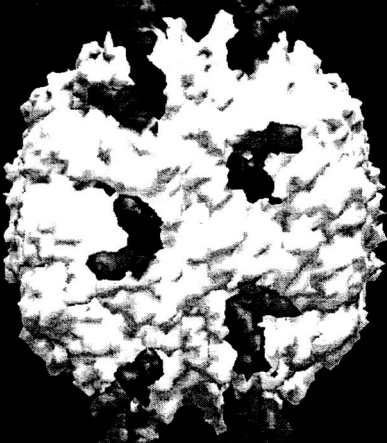
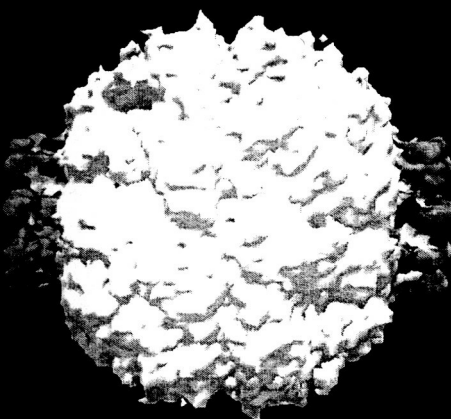
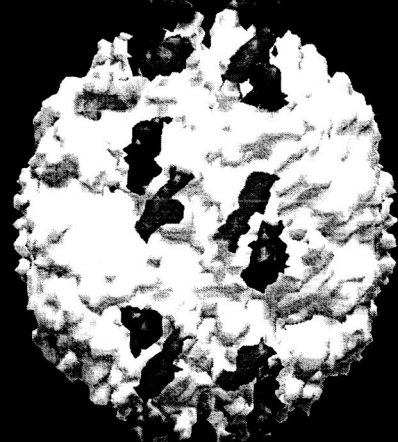








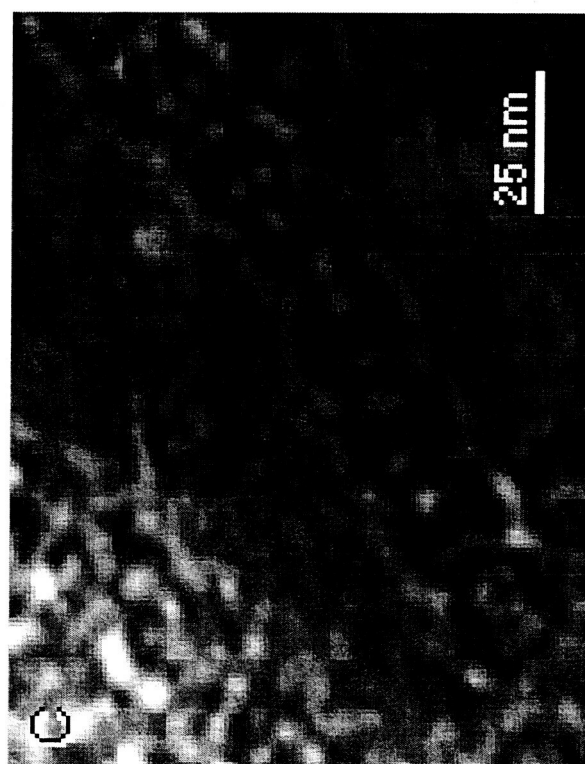
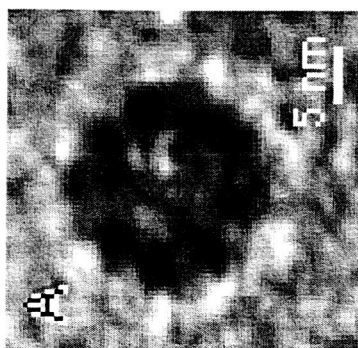
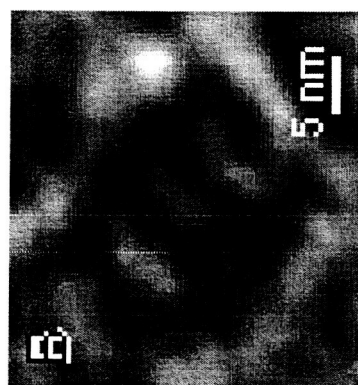
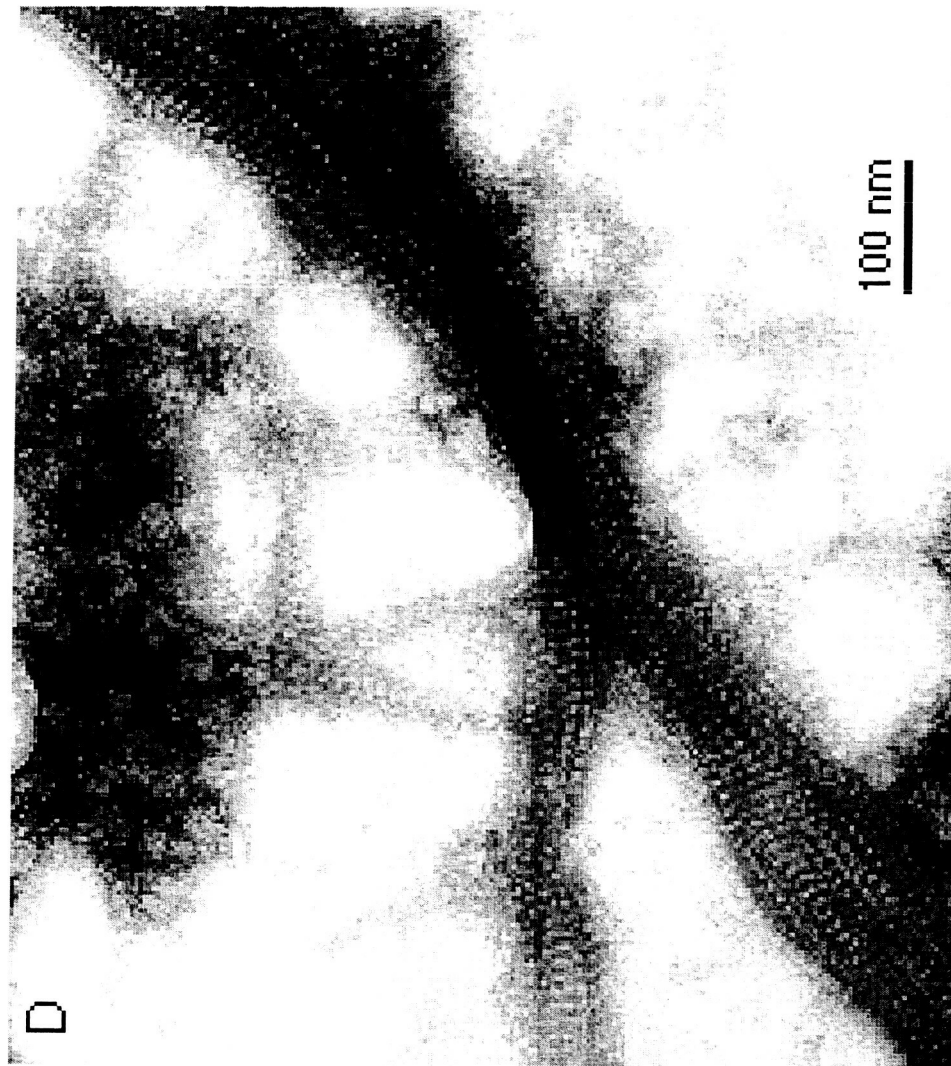




# Peptides for binding inorganics

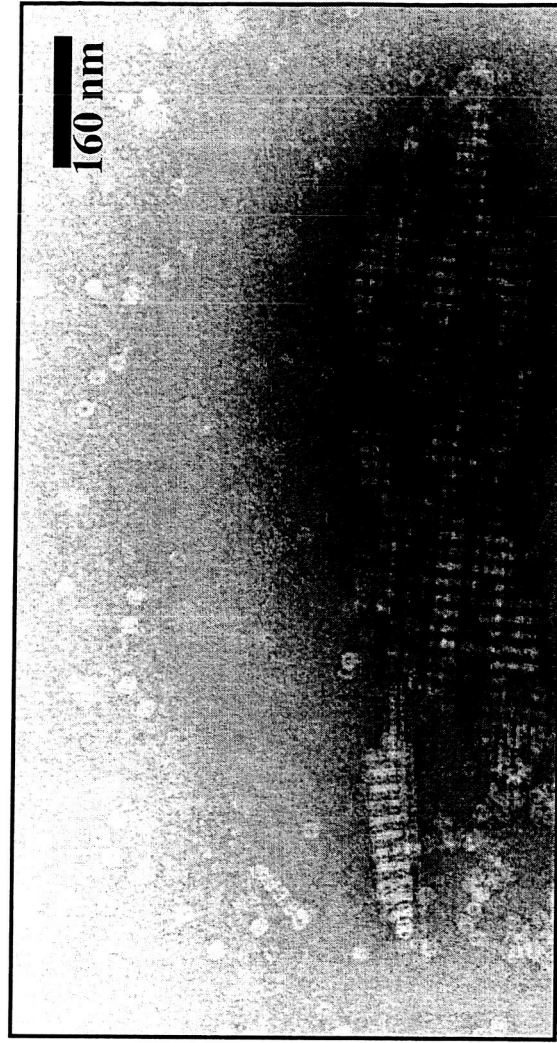
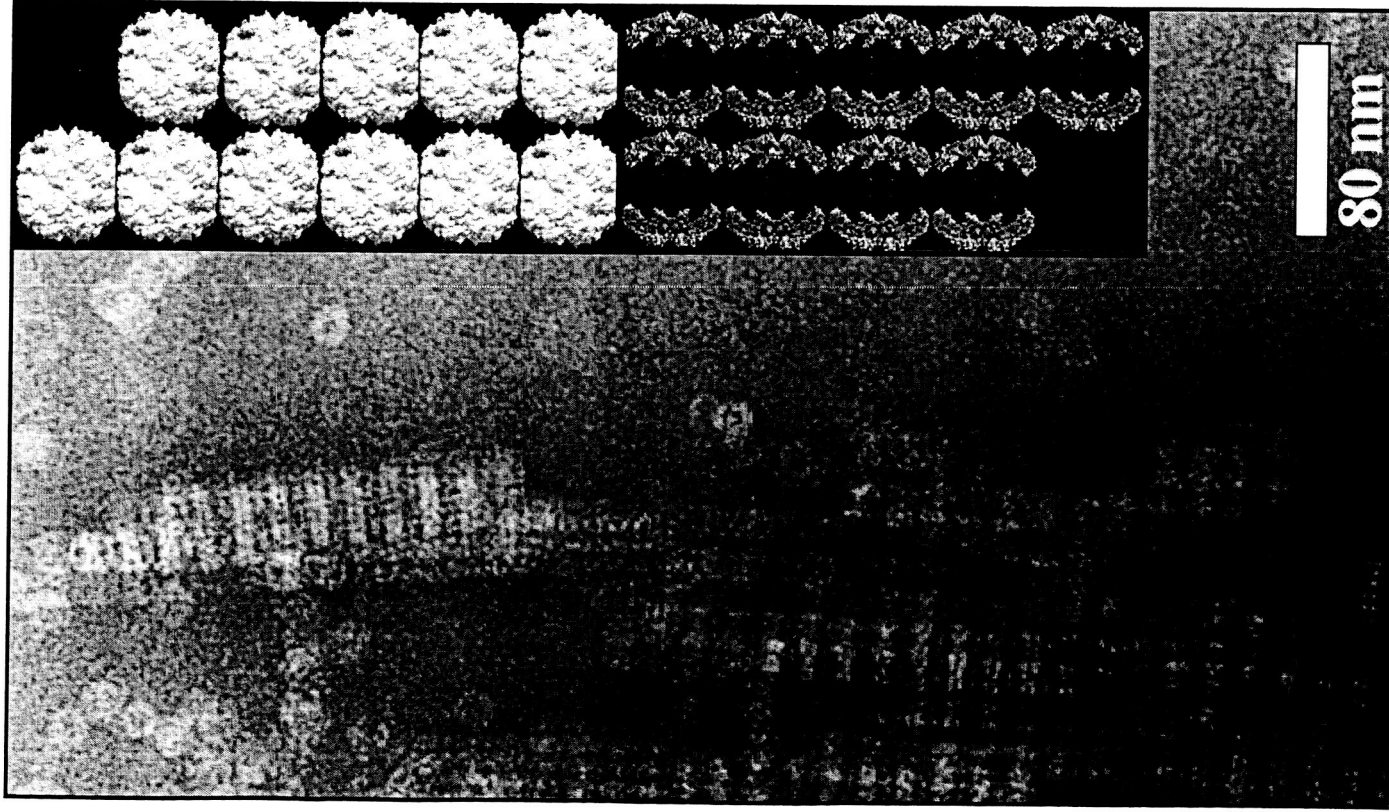
<u>material</u>	<u>sequence</u>	<u>number of residues</u>	<u>material</u>	<u>sequence</u>	<u>number of residues</u>
Au	MHGKTQATSGTIQS	14	ZnO	NTRMTARQHRSANHKSTQRA	20
	SKTSLGQSGASLQGSEKLTNG	21		YDSRSMRPH	9
	QATSEKLVGRMEGASLHPAKT	21			
Pt	DRTSTWR	7	CaCO <sub>3</sub>	HTQNMRRMYEPWF	12
	QSVTSTK	7		DVFSSFNLKHMR	12
	SSSHLNK	7			
Pd	SVTQNKY	7	Cr <sub>2</sub> O <sub>3</sub>	WRPKAATN	9
	SPHPGPY	7		RIRHRLVGQ	9
	HAPTPML	7			
Ag	AYSSGAPPMPPF	12	Fe <sub>2</sub> O <sub>3</sub>	RRTVKHHVN	9
	NPSSLFRYLPD	12		AQNPSDNNTHTH	12
	SLATQPPRTPPV	12			
SiO <sub>2</sub>	MSPHPHPRHHHT	12	GaAs	RLELAIPLQSG	12
	RGRRRRLSCRLL	12		TPPRPIQYNHTS	12
	KPSHHHHHTGAN	12		NNPMHQN	7
Zeolites	VKTQATSREEPPRLPSKHRPG	21	CNTs	HWKHPWGAWDTL	12
	MDHGKYRQKATPG	14		HHWHHWCMPHKT	12
				HWSAWWIRSNQS	12

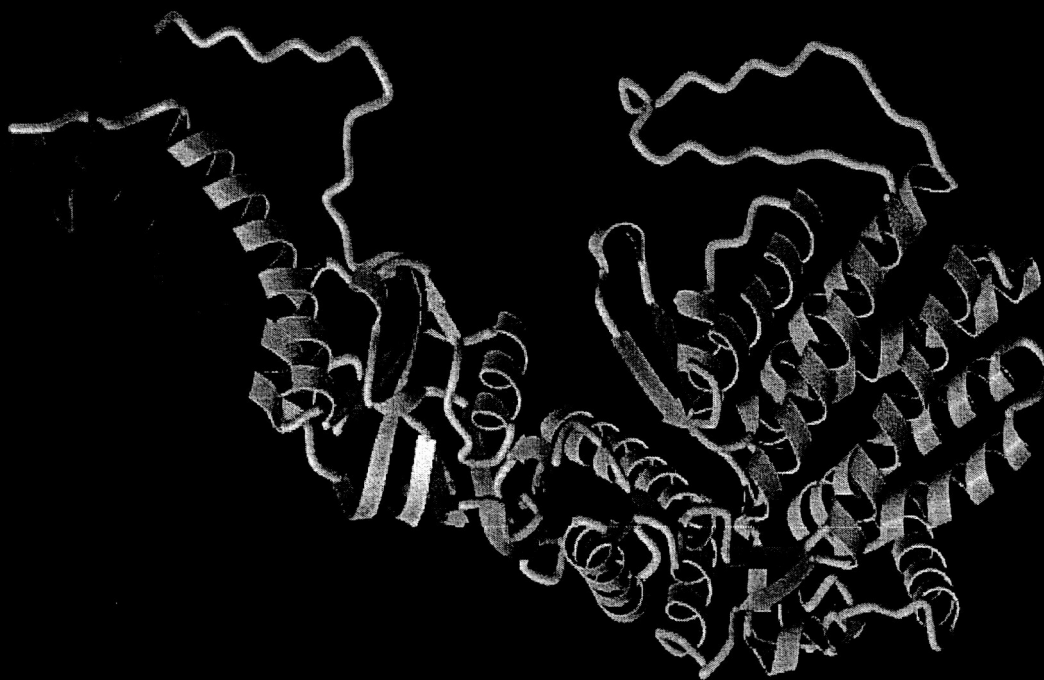
from: Sarikaya, et. al., Nature Materials

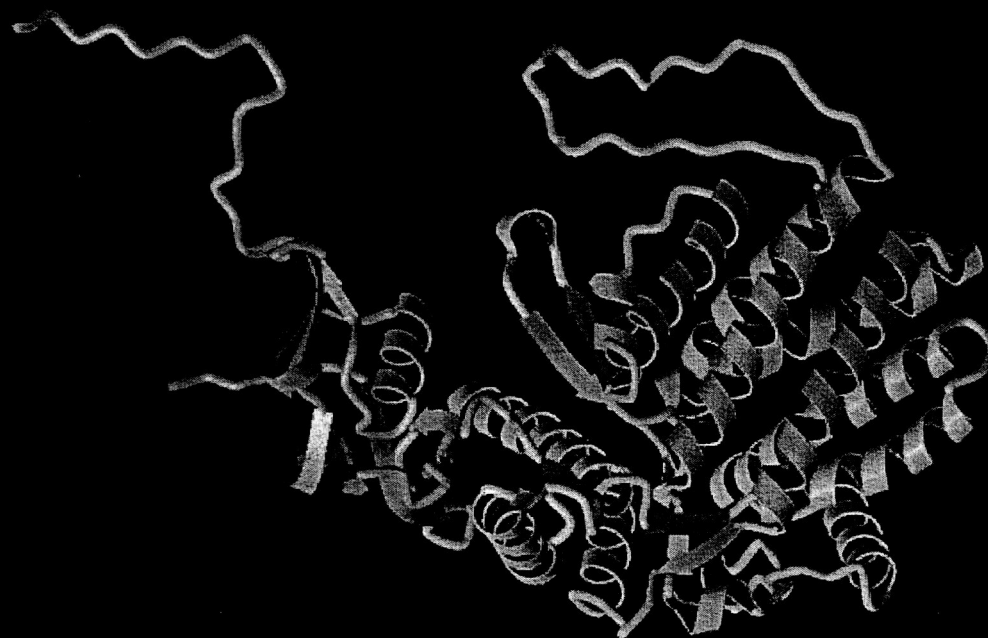




*chaperonins assemble into  
chain and bundles*







# Chaperonin filaments as nano-wires?

100 nm



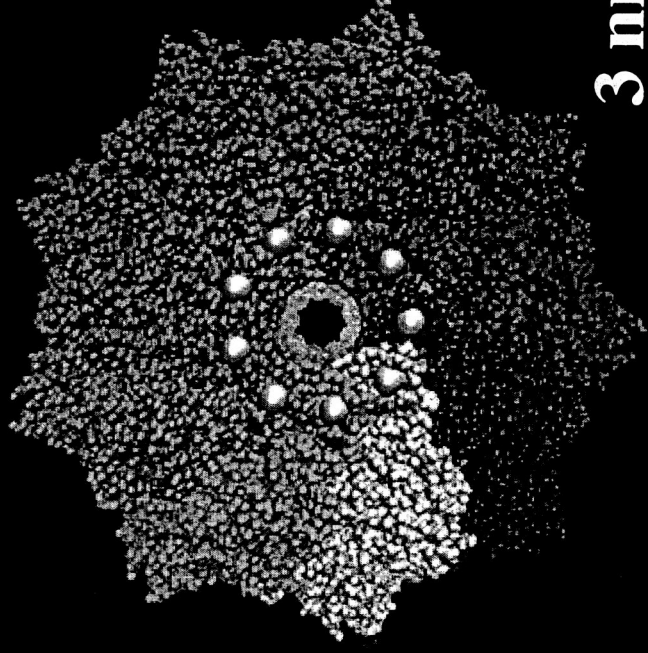
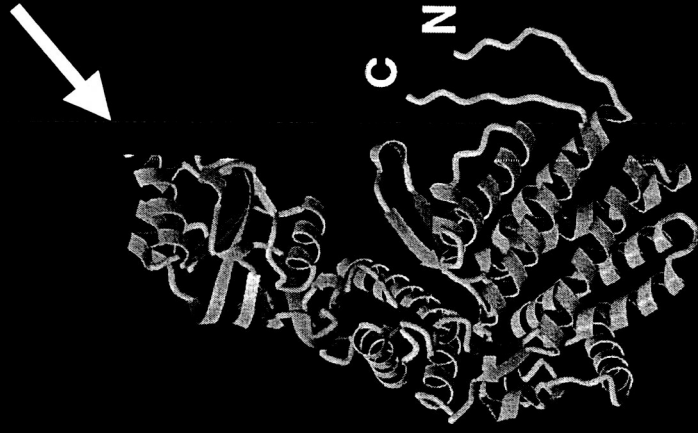




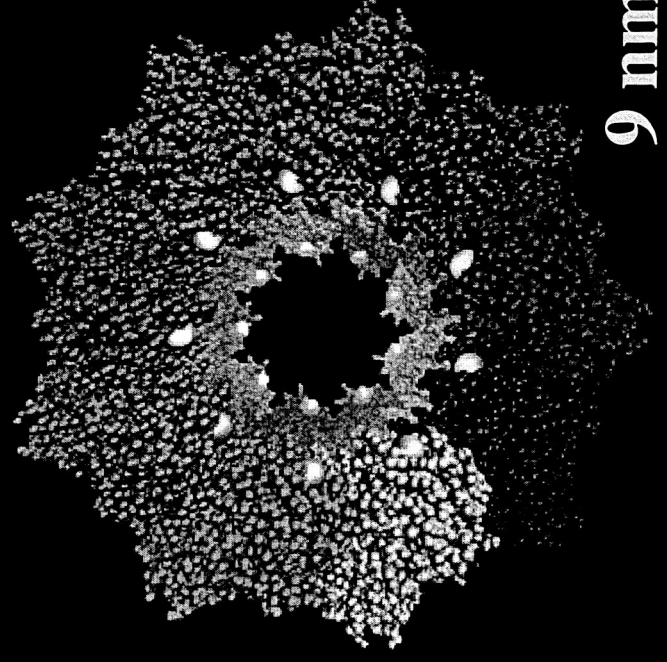




# Genetic modifications – Cys residues

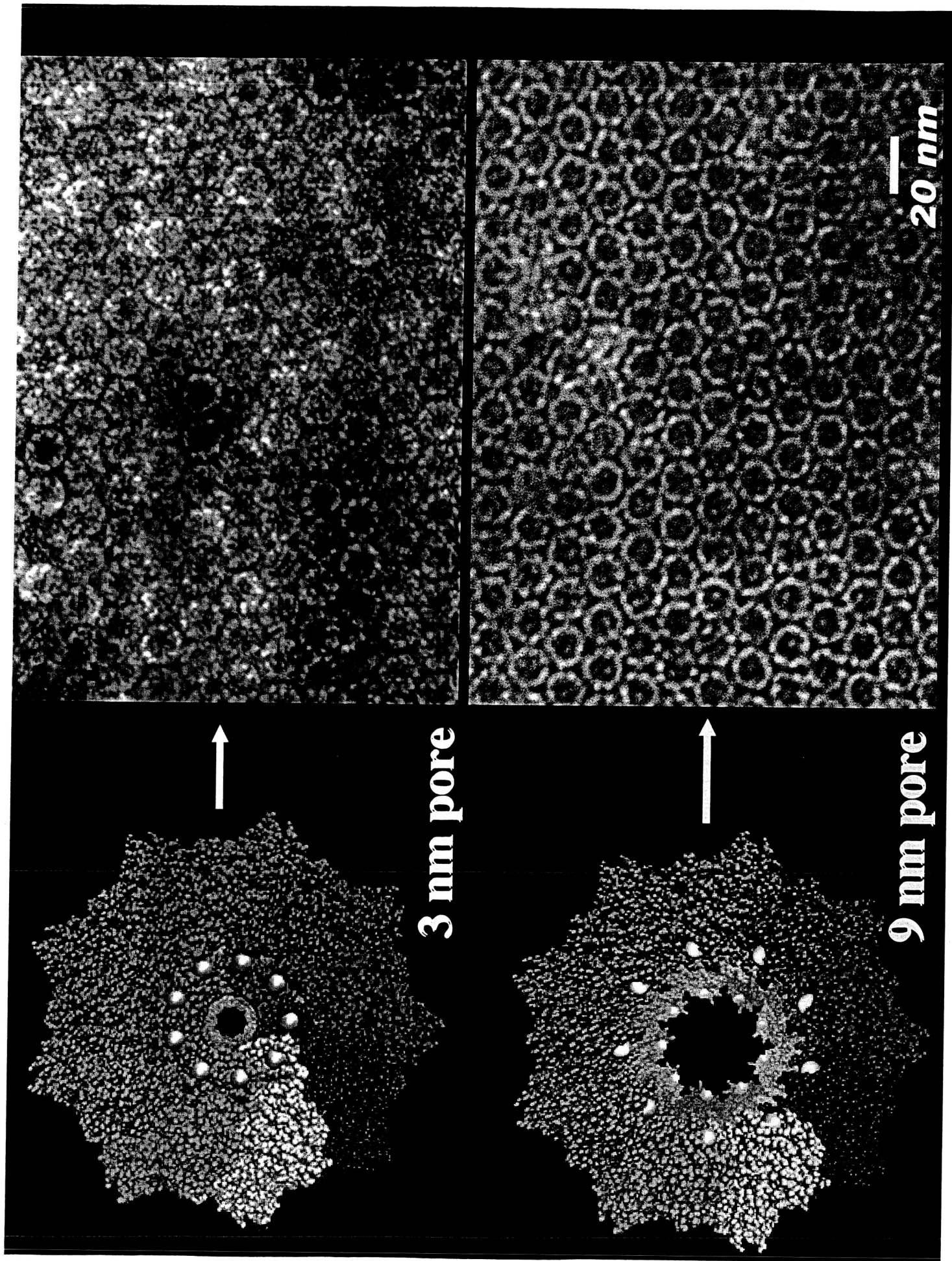


3 nm pore

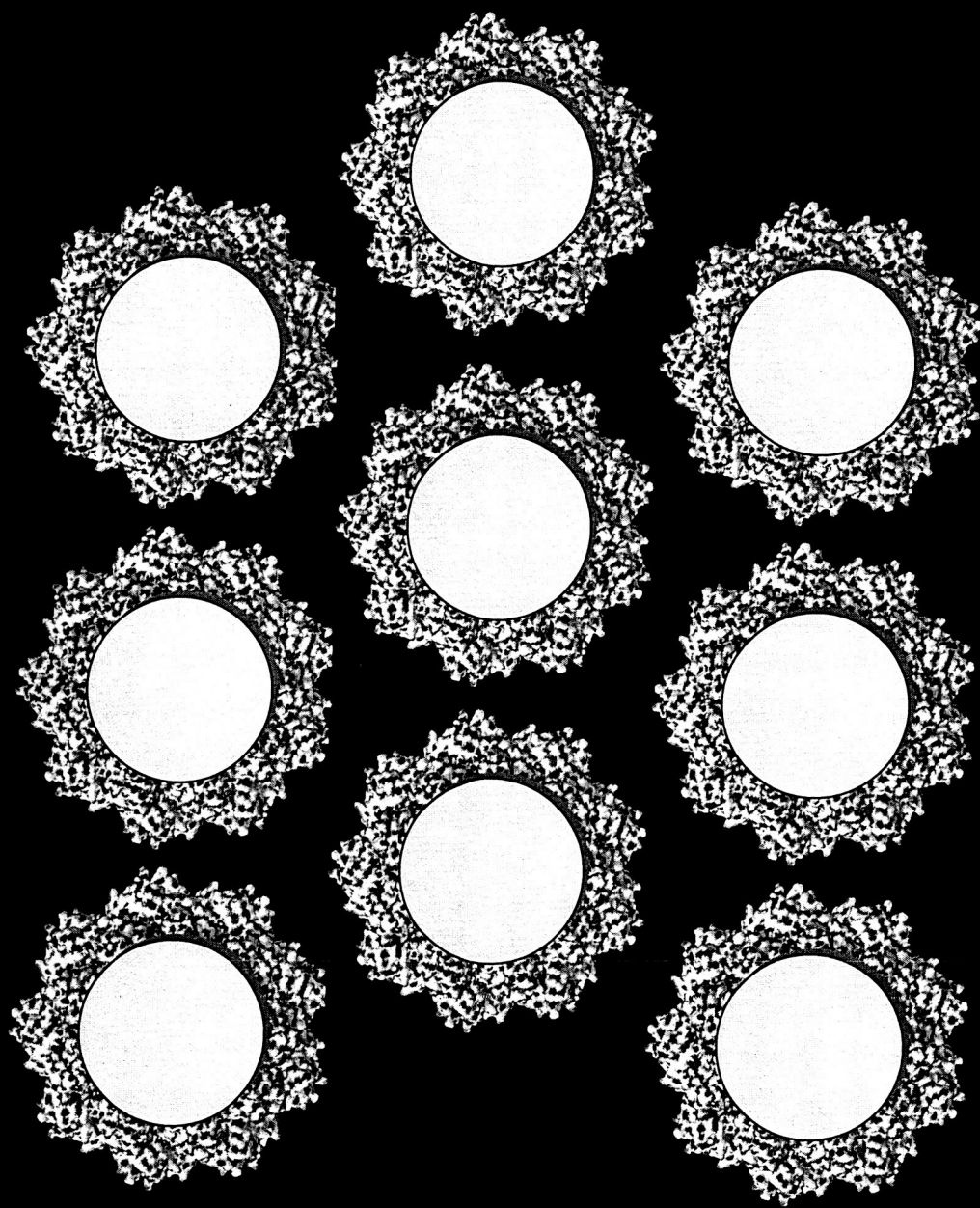


9 nm pore

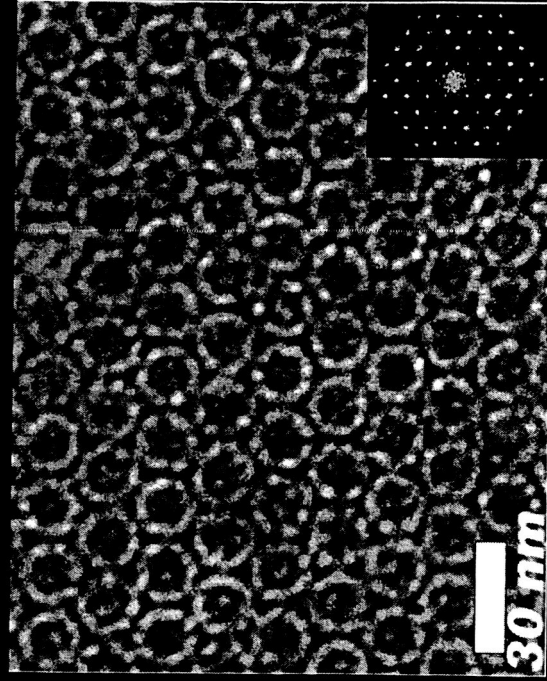




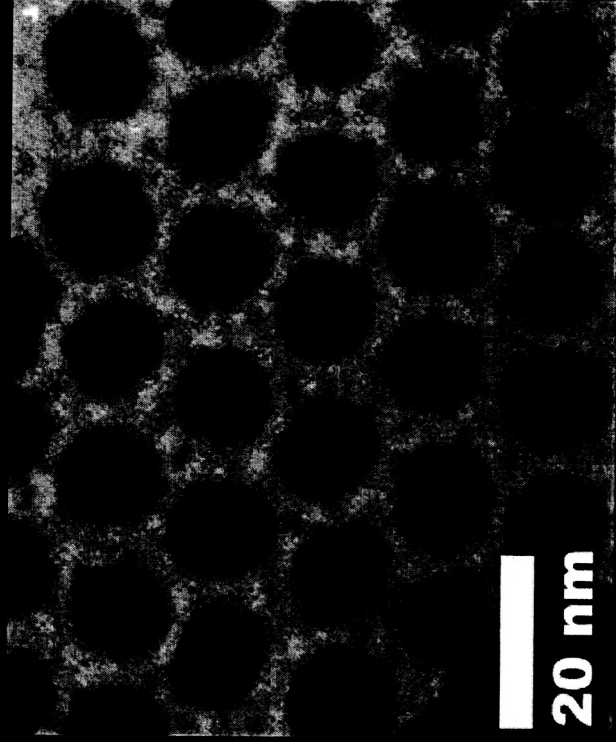
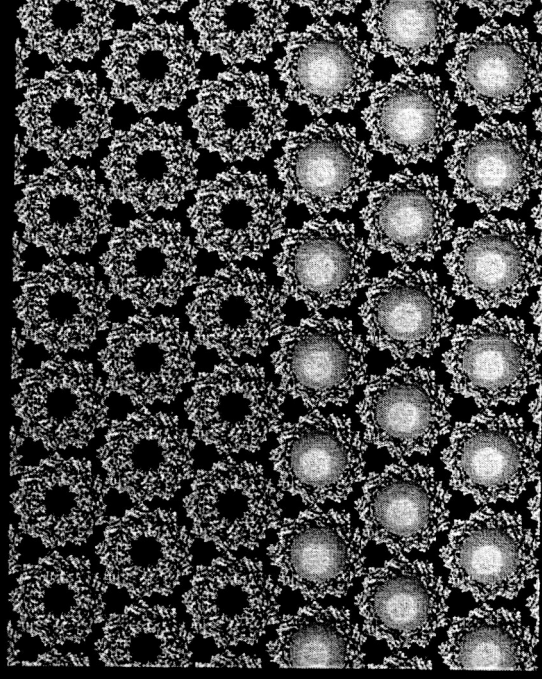




# Templates for gold nanoparticle arrays

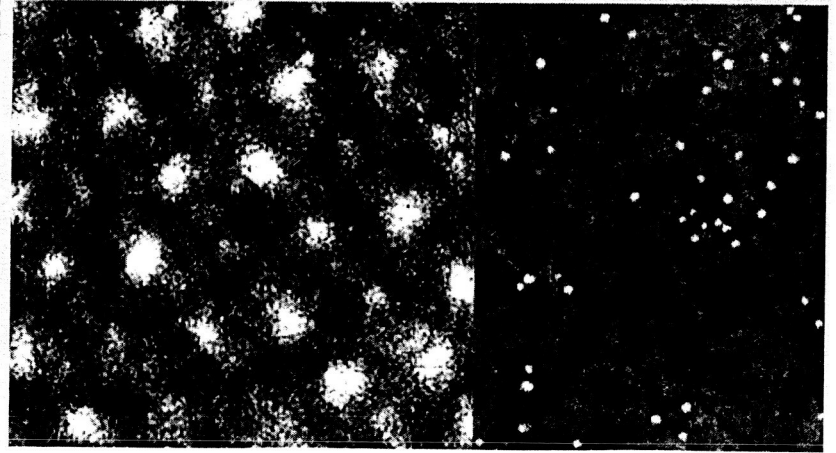
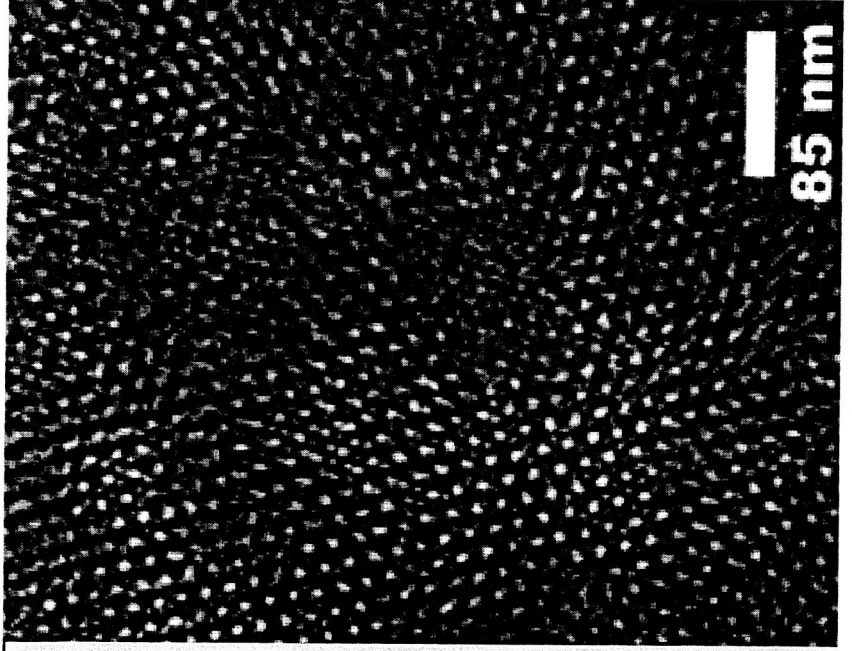
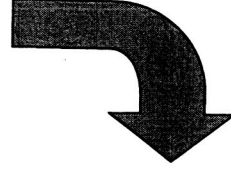
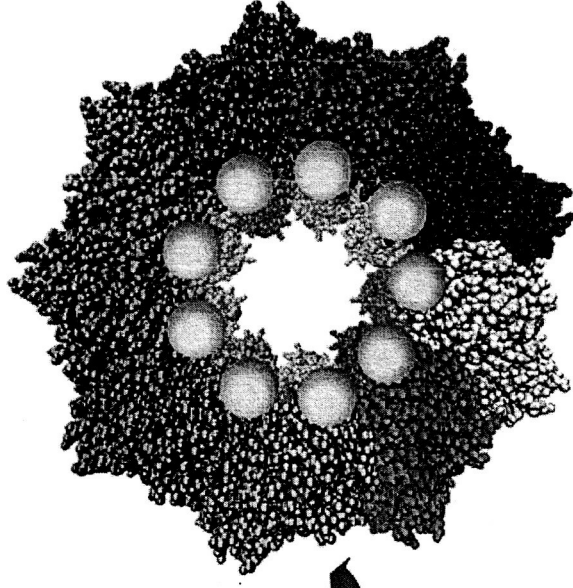
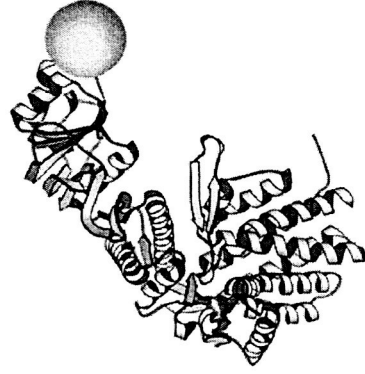
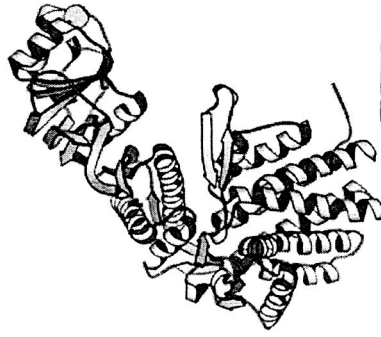
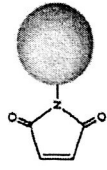


10 nm

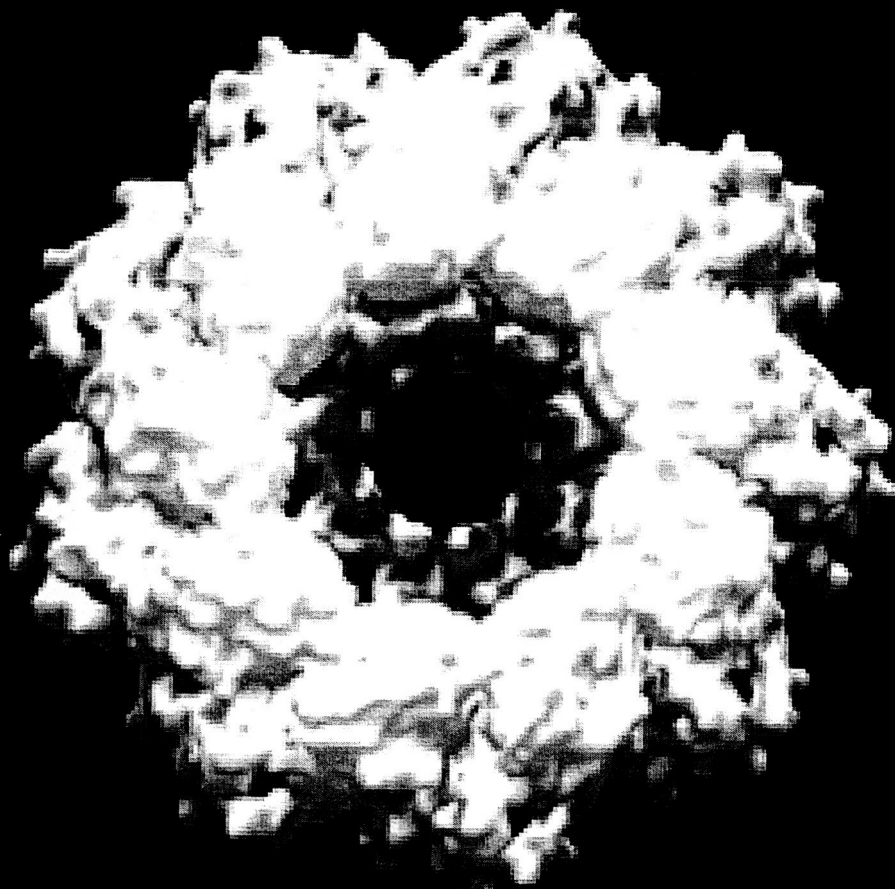


# Nanoparticle binding and assembly

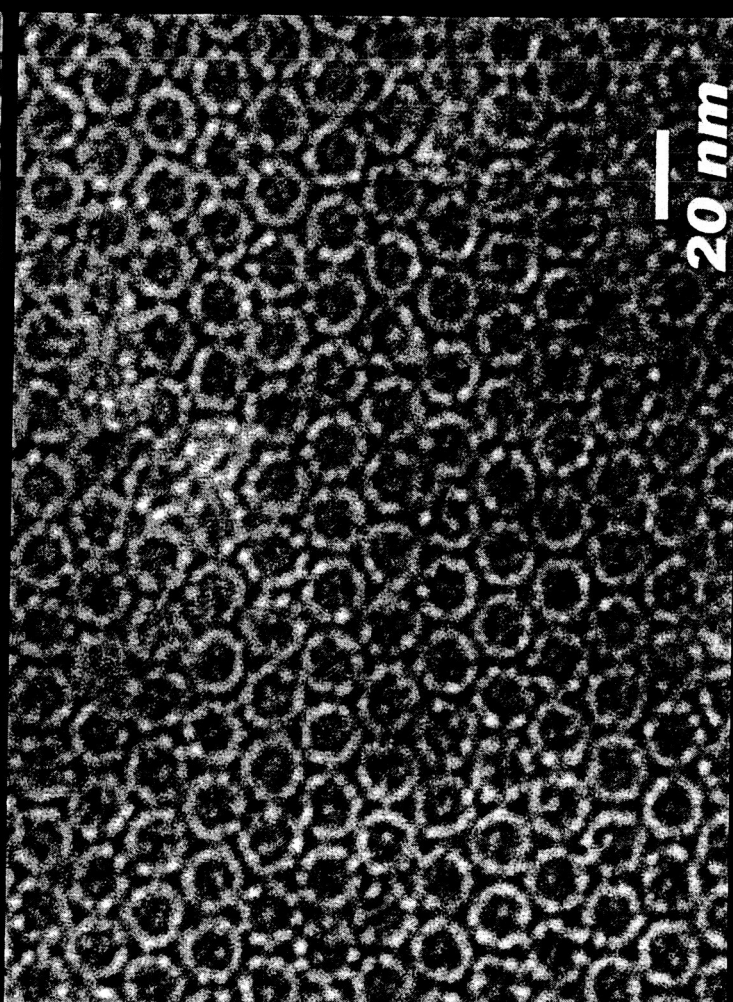
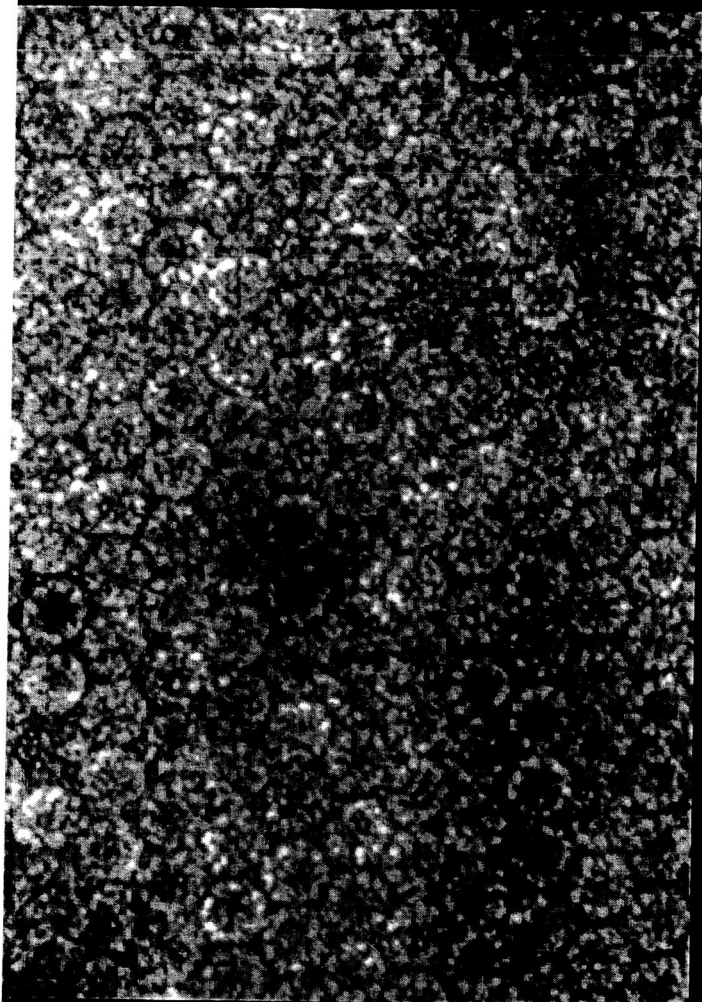
maleimido  
Nanogold



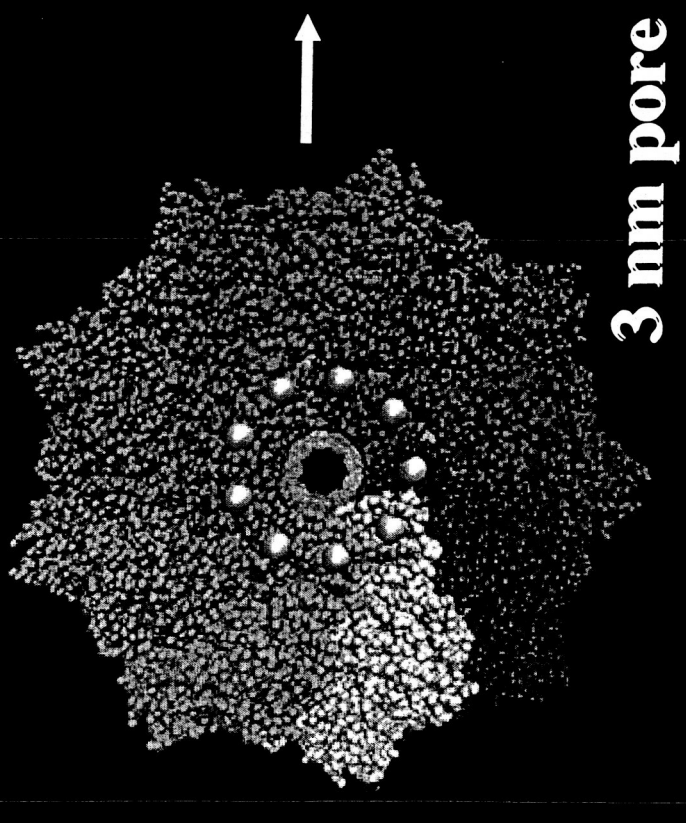
# Chaperonin rings as nano-test tubes



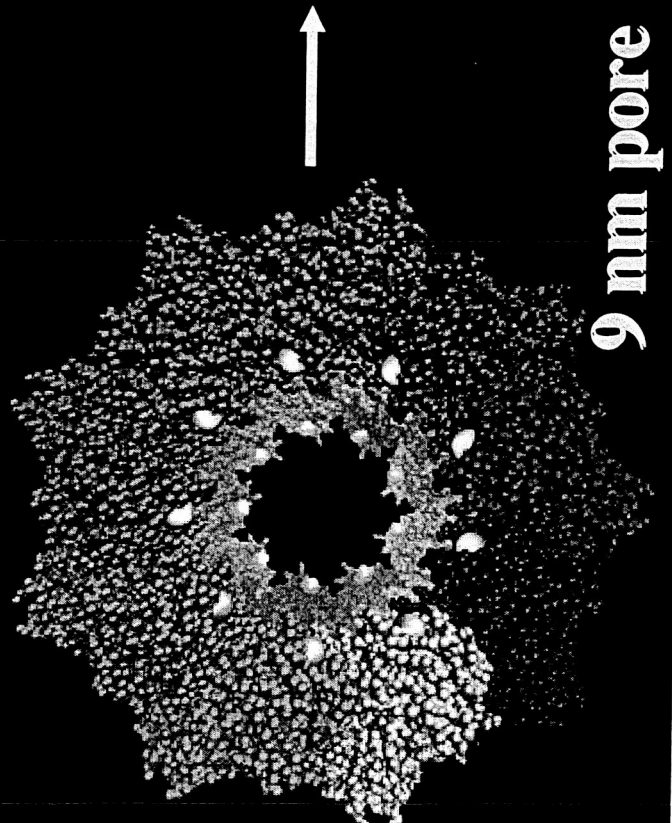




20 nm



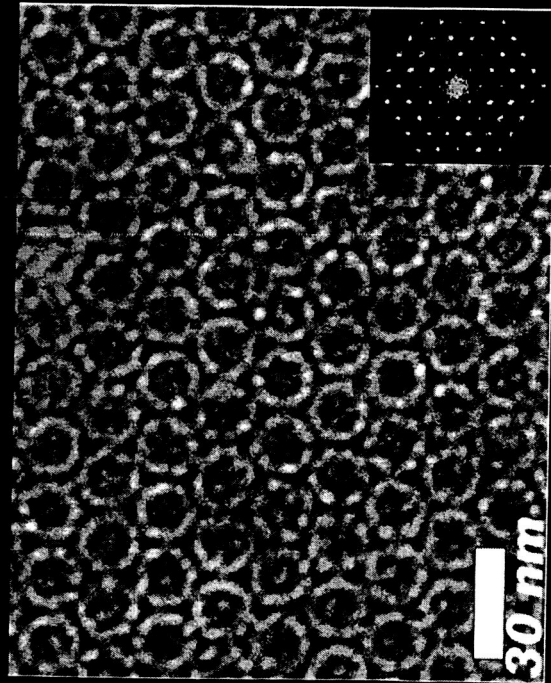
3 nm pore



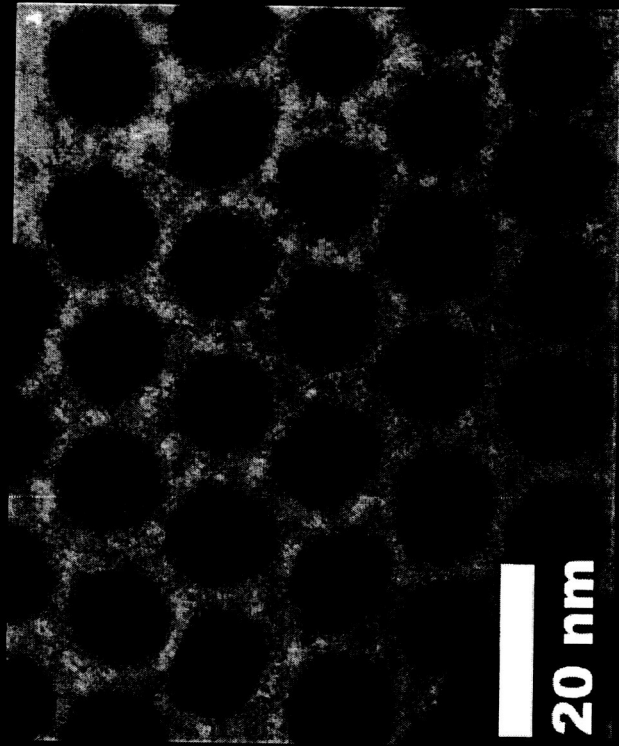
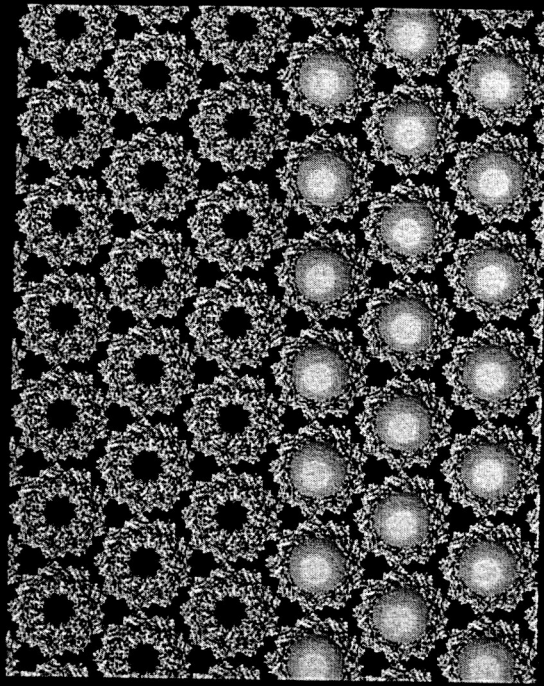
9 nm pore

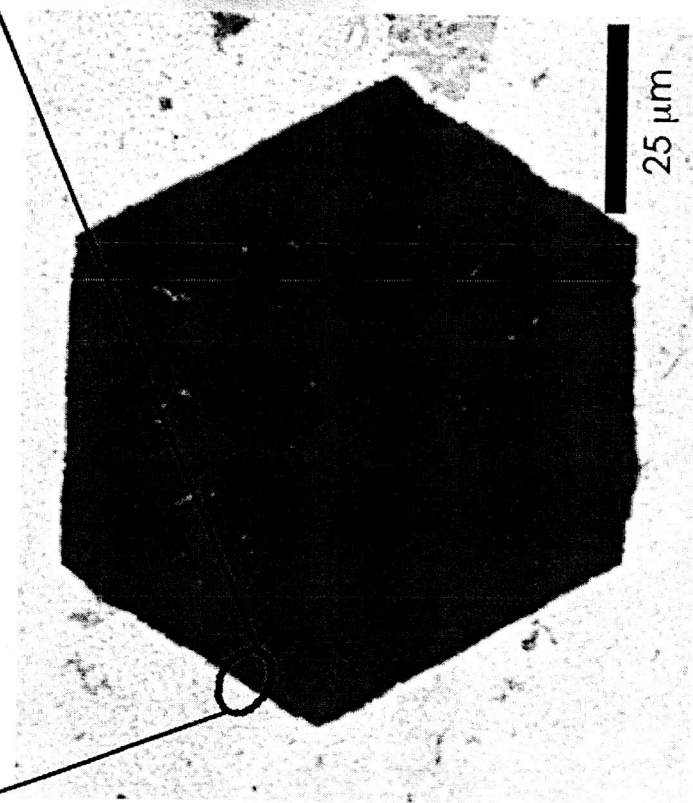
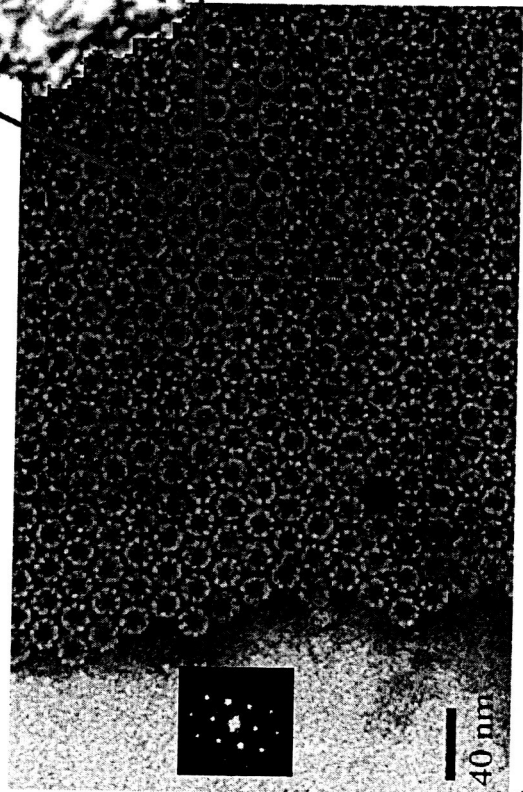
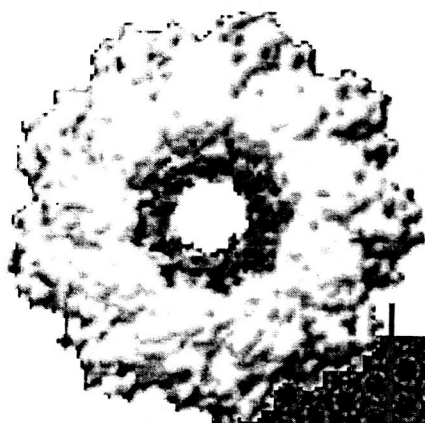
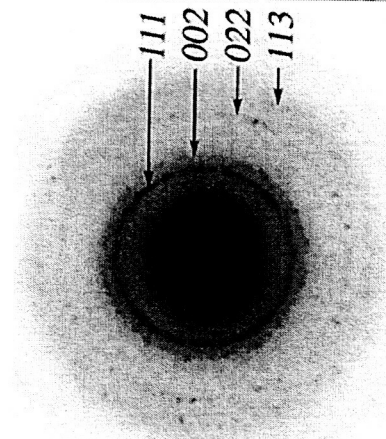
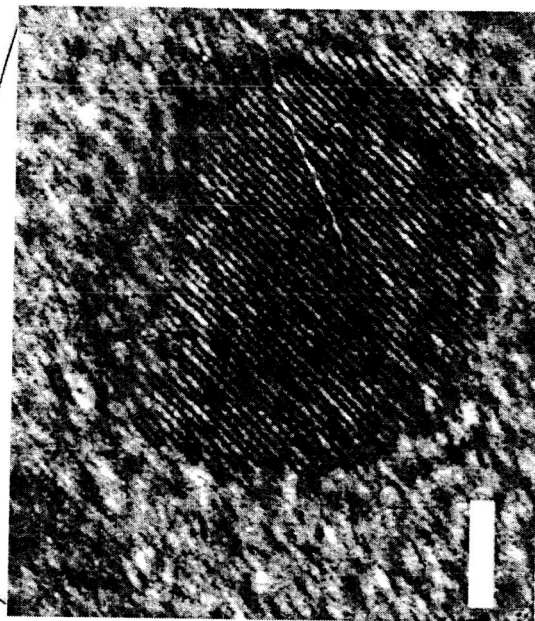
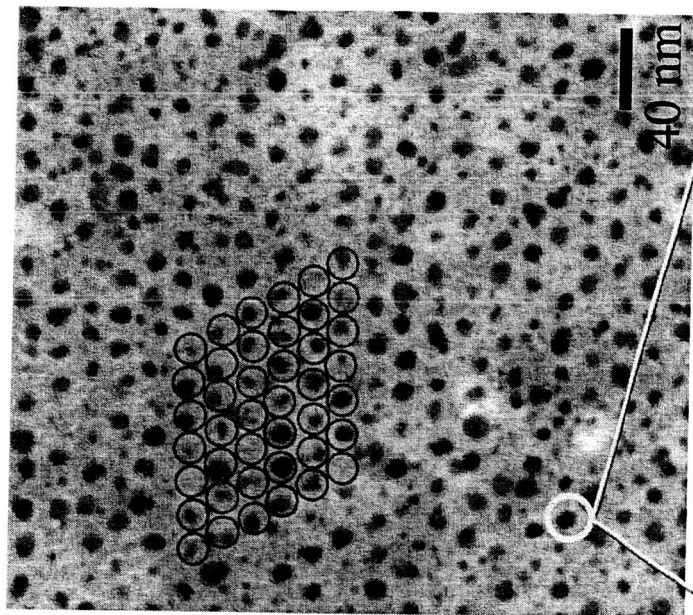


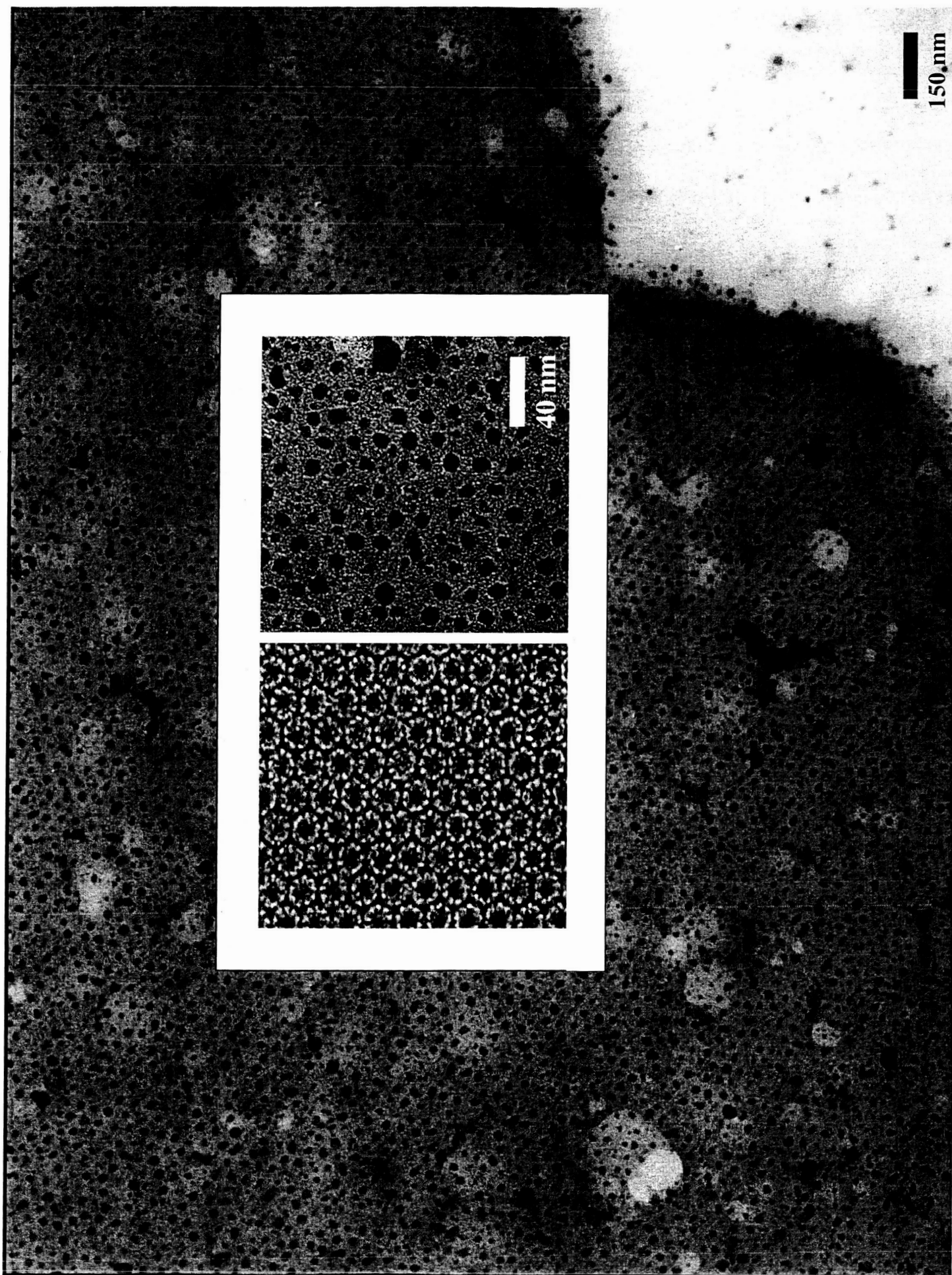
# Templates for gold nanoparticle arrays



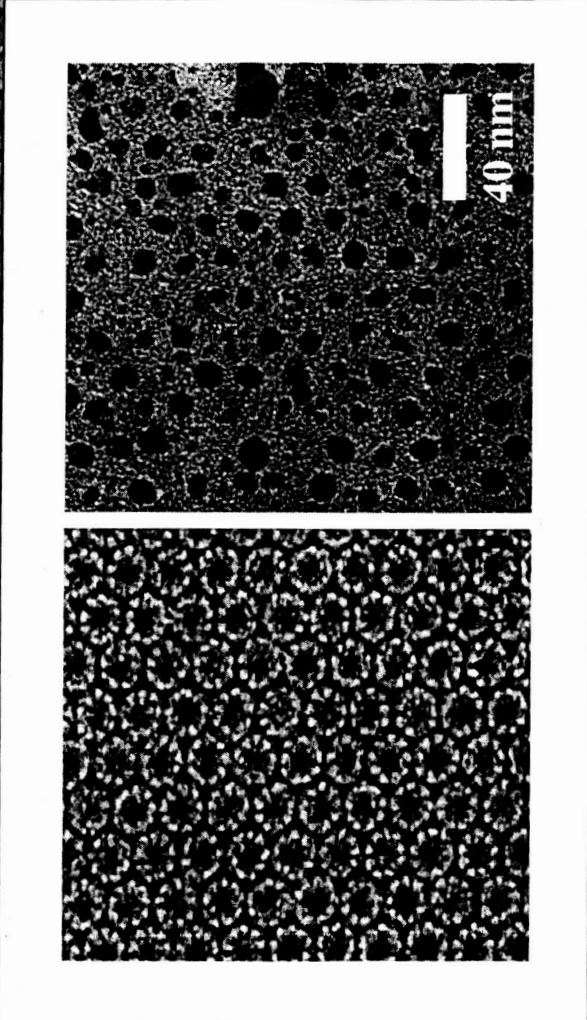
10 nm







150 nm

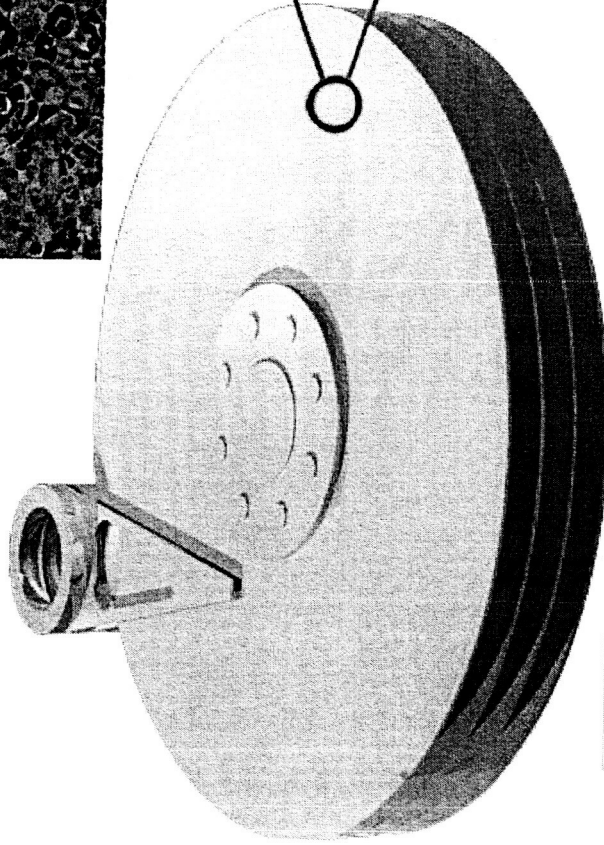
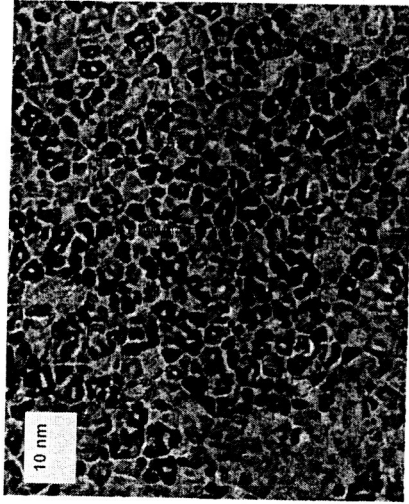


40 nm

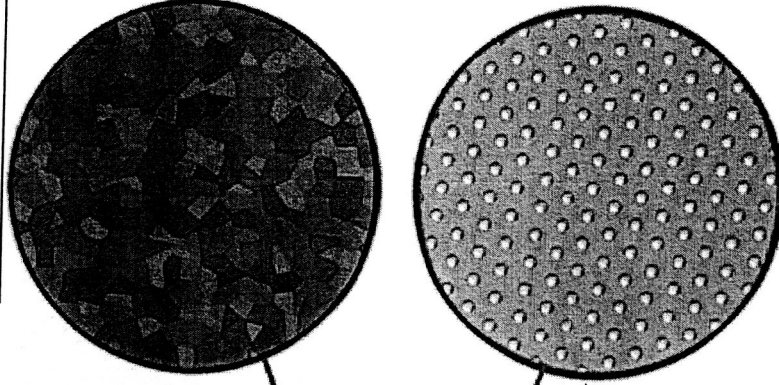


# Magnetic data storage media

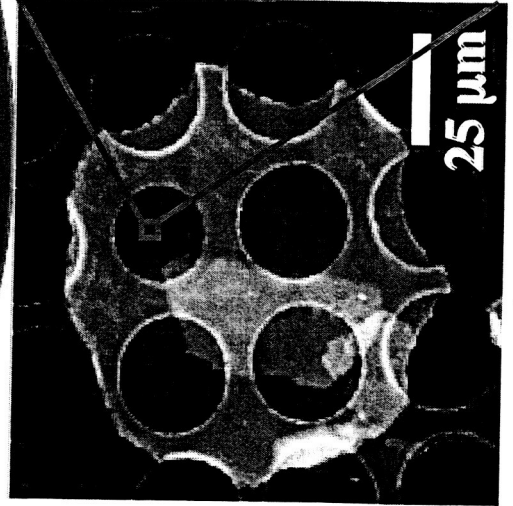
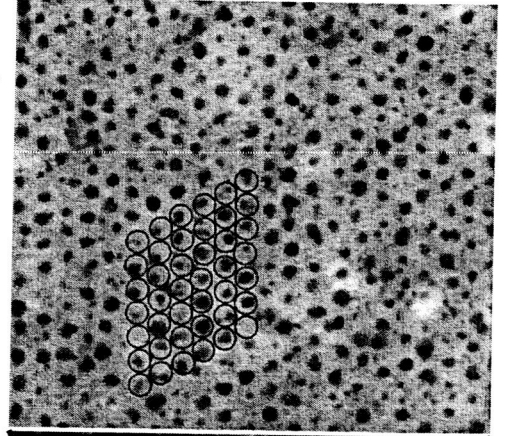
irregular geometry and close spacing of grains in conventional AFC media (image courtesy of Hitachi Global Storage Technologies, San Jose Research Center)



**Problem:**  
Irregular Grain  
Geometry of  
Conventional  
Media



**Future Solution: Patterned Media**  
–Uniform Ordered Arrays of Magnetic  
Domains for Perpendicular Recording



Tools and materials from biology to manipulate matter...



*Nano-scale bio-tools and bio-materials*  
DNA/RNA, lipids, sugars, proteins, and processes...





# Bio-Molecular-Engineering



*Why use biomolecules for nano tools  
and nano materials?*

**Because biomolecules:**

*Self-assembly*

*Molecular recognition*

*Adaptable and evolve structure & function*

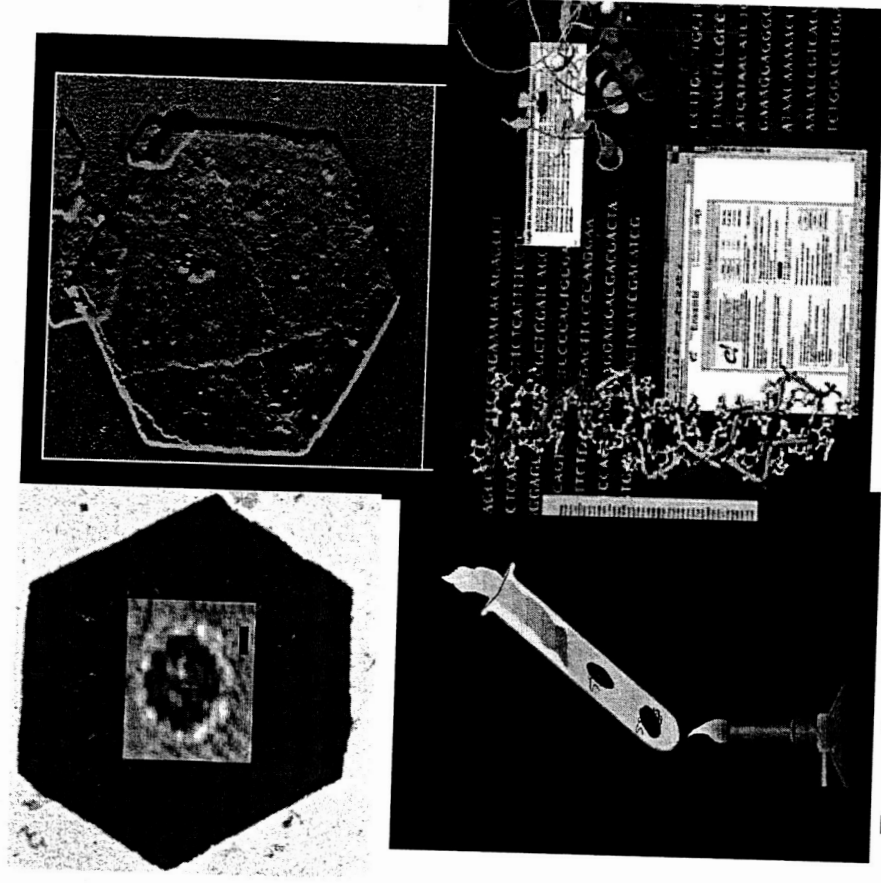
*Form dynamic or crystalline structures*

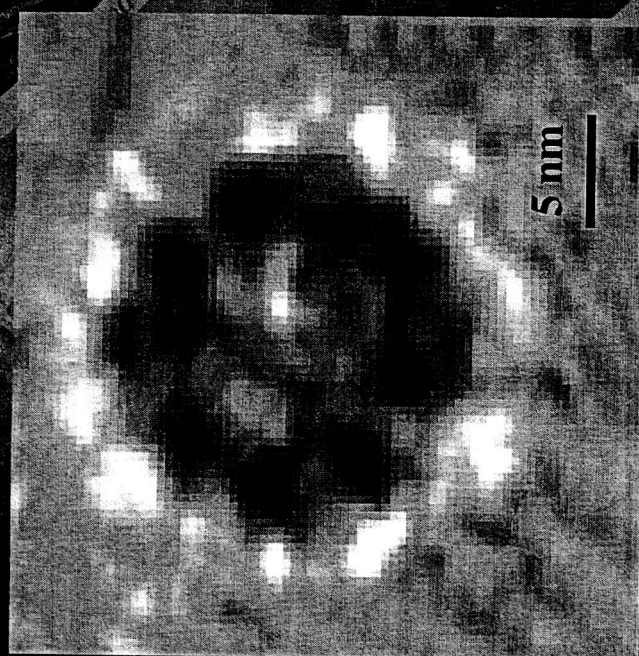
**And...**

# Bio-Molecular-Engineering

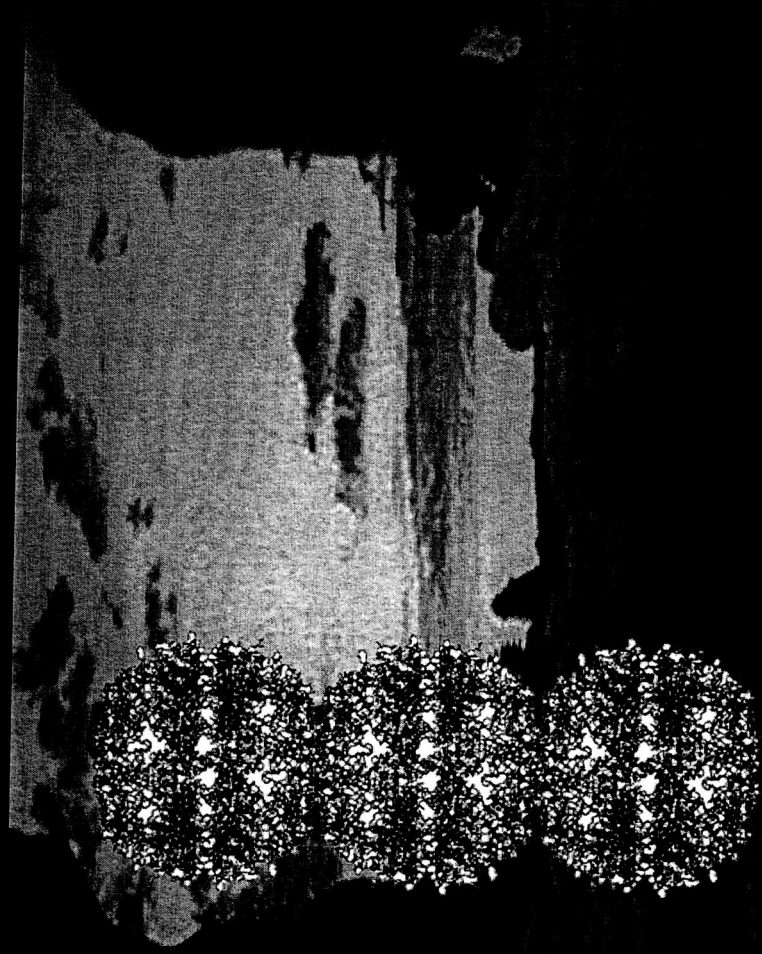
*Because: We have what we need to use them...*

- Electron microscopy
- AFM/STM
- Crystallography
- Biochemistry
- Bioinformatics
- Genomics/proteomics
- Genetic engineering
- Computation molecular design





# What is Bio-Molecular-Engineering?



## Inspiration, materials, & tools for the emerging field of 'Bioneering'.

# *Protein Nanotechnology Group*

<http://bionanex.arc.nasa.gov>

**Jonathan Trent**

*function and physiology*

**Andrew McMillan**

*synthesis of materials*

**Chad Paavola**

*protein engineering*

**Hiromi Kagawa**

**Yi-Fen Li**

**Jeanie Howard**

**Suzanne Chan**

**Kellen Mazzarella**

**Amy Ouellette**

**Amber Sanford**

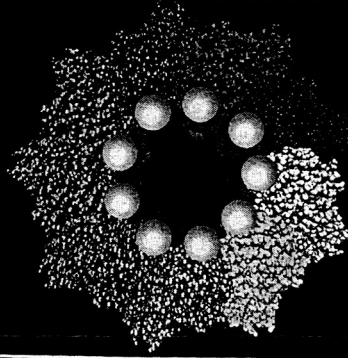
*Funding:*

NASA Ames  
Research Center

*Collaborators*

Nestor Zaluzec - Argonne National Lab  
Liz Wilson - Kubalek- Scripps Research Inst  
Mehmet Sarikaya - U. Washington  
Dan Morse - U.C. Santa Barbara

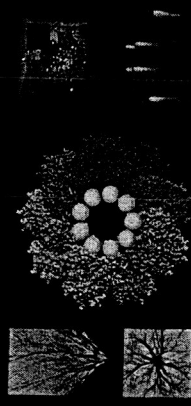
**Nanotech Briefs**



Premier Issue

**AIChE  
JOURNAL**

AN OFFICIAL PUBLICATION OF THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS  
CHEMICAL ENGINEERING RESEARCH AND DESIGN SPECIAL  
MAY 2004



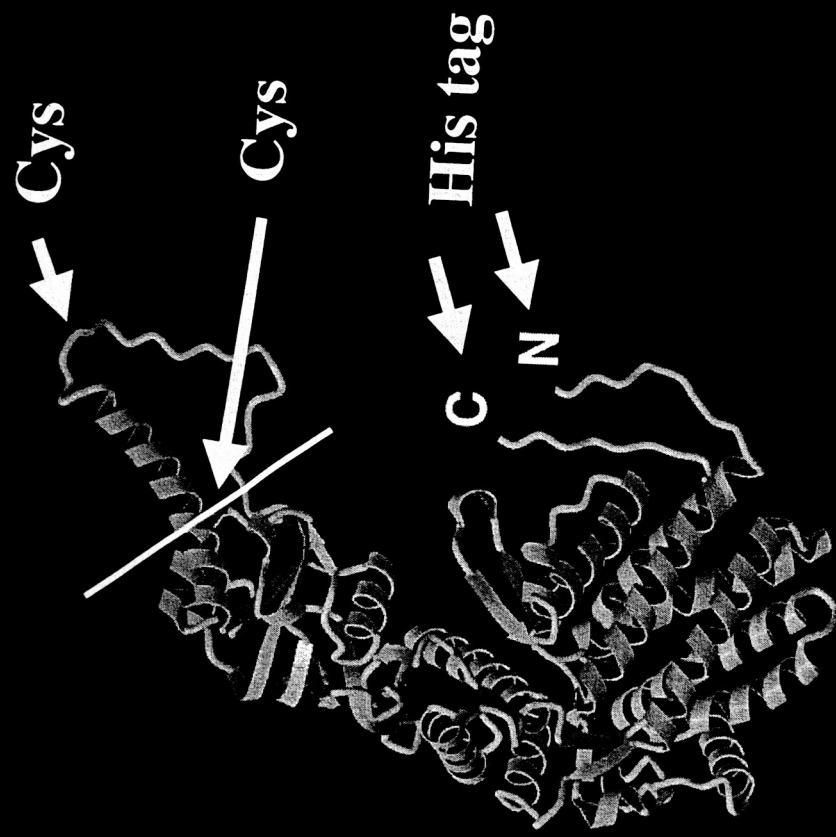
Winter 2005





**$10^{-9}$  meters = nanoscale**

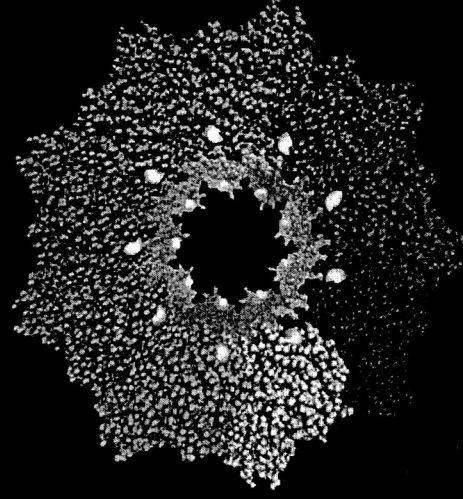
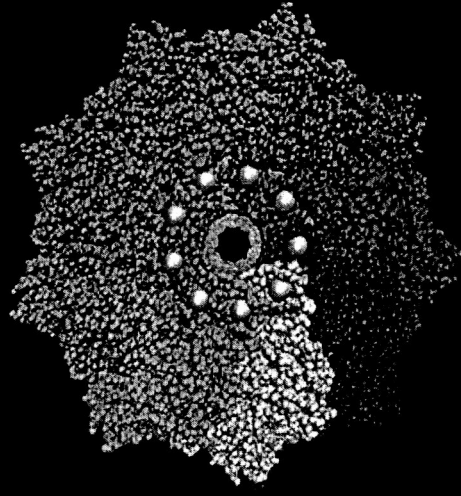
# Re-engineering the chaperonin subunit



# Using chaperonins as nano-templates

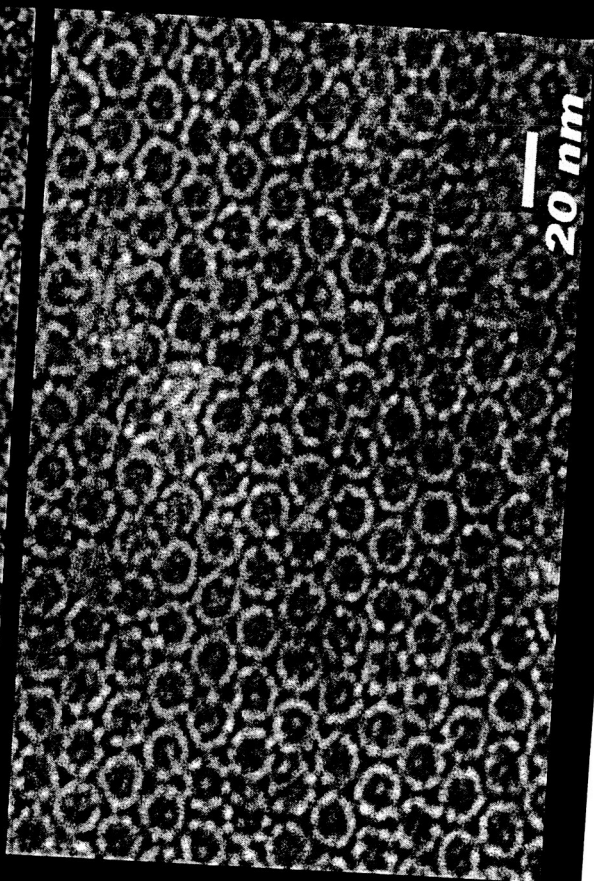
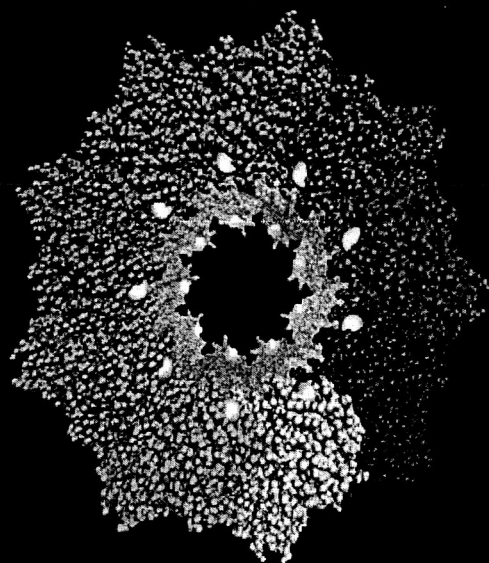
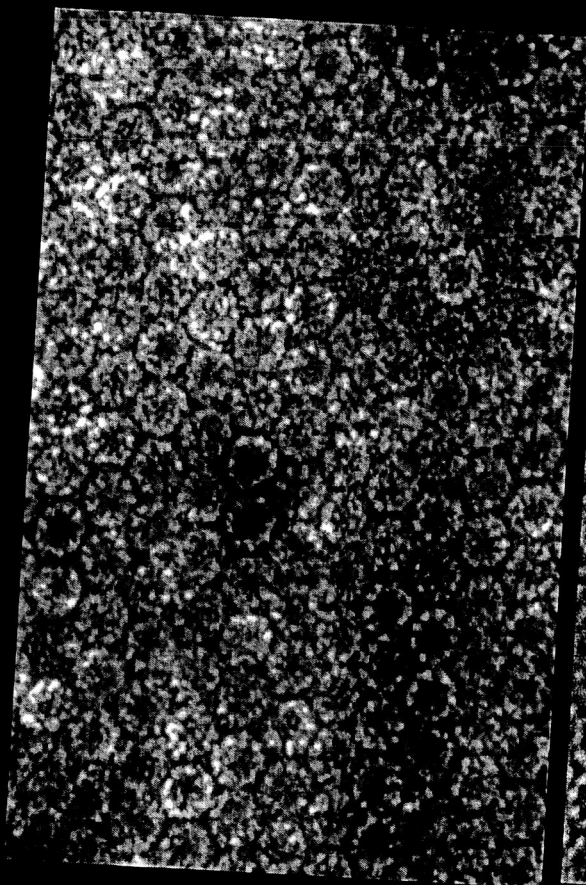
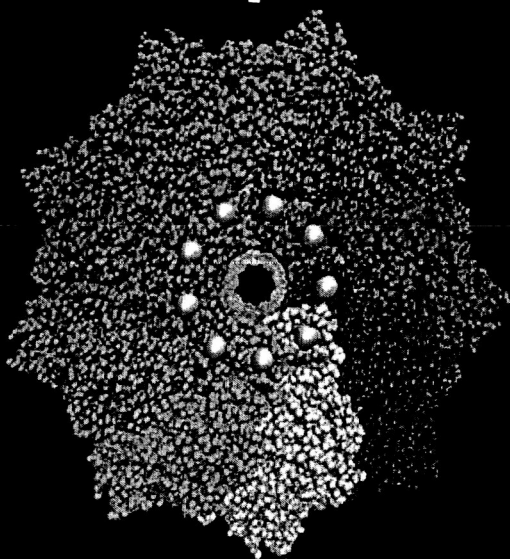


Genetic  
modifications



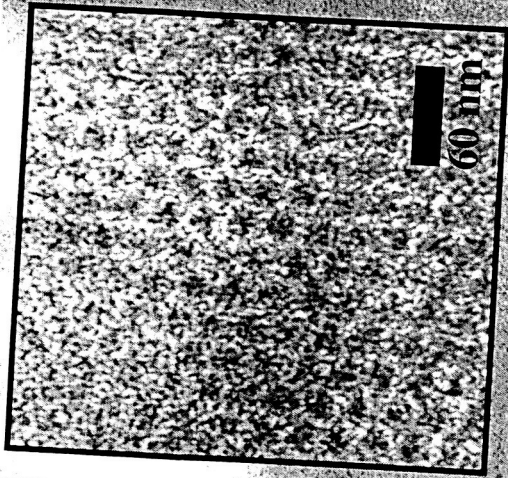
Self-  
assembly

# Higher order self-assembly

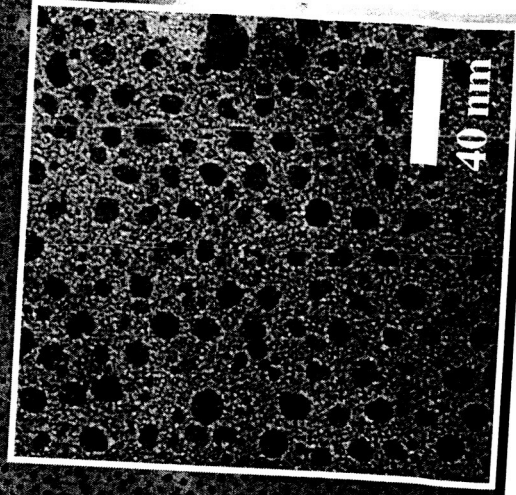




*Chaperonin crystals  
order a metal  
catalyst*



*Catalyst used to  
form magnetic  
nano-particles*



# Protein-tools for nanotechnology

## Foundations:

- \*Genetic engineering/genomics*
- \*Crystallography/proteomics*
- \*Enzymology/biochemistry*
- \*Molecular machines/biophysics*
- \*Signaling/molecular recognition*

## Medical possibilities?

- \*Diagnostics*
- \*Immunology*
- \*Devices/intervention*